REF. NO. : EX/ PG/POW/PE/T/123B/2025

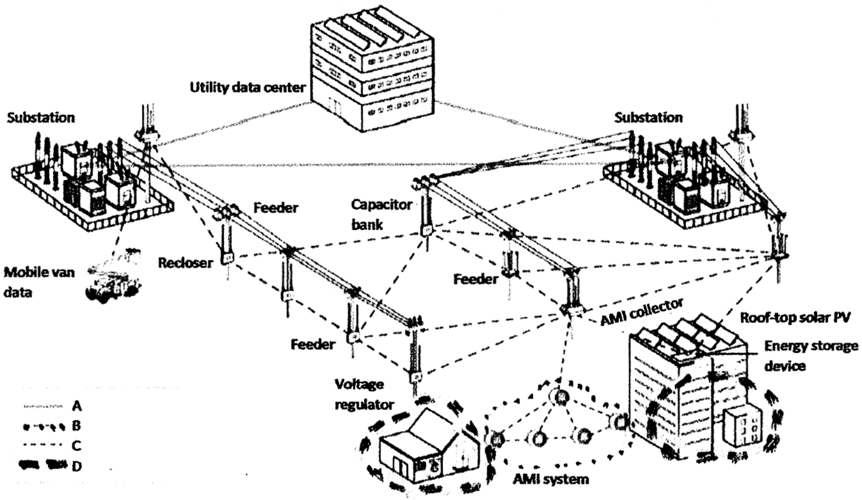
NAME OF THE EXAMINATION: **M.E. POWER ENGINEERING FIRST YEAR SECOND SEMESTER - 2025**

SUBJECT: **SMART GRID TECHNOLOGIES**

TIME: 3 HOURS **FULL MARKS: 100**

CO1: Define smart grid, identify its benefits vis-à-vis conventional grid, and outline the socio-environmental-economic benefits under the aegis of standards and protocols (K1, K2, K5)
CO2: Apply the concepts of modern communication and computational tools for implementation of smart grid operation, control and protection technologies (K3, K4)
CO3: Assess the benefits and challenges of integrating distributed energy resources, energy storage, and electric vehicles to smart grid (K3, K4, K5)
CO4: Evaluate the impacts of power market, environment, and socio-economic standing on smart grid implementation (K4, K5)

Answer Q1, and any EIGHT (8) questions from the rest

[Q1]	***Choose the correct option(s) for any TEN (10) of the following*** ***[10@2 = 20]***
(i)	The components of a power transfer system are: (1) Generator (2) Step-up power transformer (3) Primary customer (4) Step-down power transformer (5) Generating substation (6) Transmission line (7) Domestic customer (8) Distribution substation (9) Distribution transformer (10) Distribution line. The hierarchical order in which power is transferred from generation to your home is: (a) 1-2-6-4-3-10-7 (b) 1-5-2-6-4-8-3-10-9-7 (c) 1-5-2-6-8-4-10-9-7 (d) 1-2-6-4-9-10-7
(ii)	Key features of the distribution domain in smart grid are: (a) Substation automation (b) Low voltage relays and circuit breakers (c) Increasing use of DERs & their coordination (d) Distribution management system (DMS) (e) Wide area measurement system (WAMS) (f) Communication infrastructure (g) Distribution transformer (h) Distribution automation
(iii)	Smart Grid Technology comprises of the following: (a) AMI, AVR, LFC, Renewable Integration (b) DR/DSM, Distribution Automation, GPS (c) MDM, WAMS, SCADA, Cyber security (d) OMS, EMS, EM Relays, Flat-rate tariff
(iv)	Identify the communication protocols used in Outage Management System (OMS) in smart grid:  The correct order of A, B, C, D communication protocol is (a) Core IP Network, FAN, NAN, HAN (b) WAN, NAN, FAN, HAN (c) Core IP Network, WAN, FAN, HAN (d) Core IP Network, WAN, NAN, HAN

[Turn over

(v)	What are the main goals of Automatic Generation Control (AGC) in smart grid? A. keep overshoot and settling time of the governor within the acceptable ranges B. curtail load so as to match supply with demand C. keep the voltage and frequency of supply within specified tolerance band D. keep the operating frequency under prescribed limits E. maintain the interchange power between grids through tie-lines at the intended level The correct combination is (a) A, C, D, E (b) A, D, E (c) A, B, C (d) B, C, D
(vi)	Attributes of SCADA for Distribution Management System (DMS) in smart grid are: A. Meter reading and bill generation B. Data storage, event log, analysis and reporting C. Data acquisition D. Monitoring, event processing and alarms E. Control The correct combination is (a) A, C, D, E (b) B, C, D, E (c) A, B, D, E (d) A, B, C, D
(vii)	The main components of Wide Area Monitoring System (WAMS) in Smart Grid are: A. Data storage B. Communication networks C. Application software D. FACTS Devices E. Phasor Data Concentrators (PDCs) F. Phasor Measurement Units (PMUs) G. Smart Energy meter H. Programmable Logic Controller (PLC) The correct combination is (a) C, D, E, F, H (b) B, C, D, F, H (c) A, B, C, E, F (d) A, C, F, G, H
(viii)	Match the elements of List X with those of List Y in relation to RES forecasting: *List X: (i) Statistical approach, (ii) AI approach, (iii) Physical approach, (iv) Hybrid approach* *List Y: (A) JAYA-SVM (B) ARIMA (C) SVR (D) ARMAX (E) Satellite-image (F) ANN (G) NWP (H) SARIMA-SVM* (a) i - A, ii – C, iii – G, iv – F (b) i - B, ii – F, iii – E, iv – G (c) i - D, ii – C, iii – G, iv – A (d) i - D, ii – F, iii – B, iv – H
(ix)	Some functions of Meter Data Management (MDM) in smart grid are: A. Direct load connect/disconnect B. Demand Control/Demand Response Support C. Reporting D. Billing Calculations E. Alarm Generation F. Smart meter firmware update G. Data Validation, Estimation, and Editing (VEE) The correct combination is (a) B, C, D, E, G (b) A, C, E, F, G (c) B, C, D, E, F (d) A, B, D, F, G
(x)	Some of the technical challenges of Renewable Energy Source (RES) integration to power grid are: A. Interfacing B. Investment cost C. Uncontrolled variability D. Congestion management E. Cost allocation F. Voltage and frequency regulation G. Effect on power market H. Storage needs The correct choices are (a) A, B, D, G, H (b) B, C, E, F, G (c) A, C, D, F, H (d) B, D, E, G, H
(xi)	Some of the requirements of Energy Storage System (ESS) for making it grid-compatible are: A. Reliability B. High energy density C. Water-proof D. Long life-cycle E. Cost-effectiveness F. Light-weight G. Large capacity H. Environmentally less harmful The correct choices are (a) A, B, D, E, F, H (b) A, C, D, E, G, H (c) A, C, D, F, G, H (d) A, B, D, F, G, H
(xii)	If you are the CEO of CESC, what up gradations you should plan in you power distribution infrastructure so that the CESC grid becomes compatible to large scale deployment of plug-in electric vehicles (PEVs) among your consumers?

	A. Managing the load balancing, peak hour shaving, off-peak charging, tariff structure and economic and cost-effective user billing infrastructure B. Manufacture energy efficient batteries C. Upgrade to smart grid so that PEV batteries in V2G mode can be used as distributed storage during excess RES generation hours D. Manage PEV charging facilities so that the grid is not over-burdened due to rush-hour charging E. Upgrade to smart grid so that PEV batteries G2V mode can be used as distributed generation sources during peak-load periods thereby reducing burden on conventional generating plants The correct combination is (a) A, B, C, E (b) A, C, D, E (c) A, B, C, D (d) B, C, D, E
(xiii)	Choose the appropriate decision-making activities corresponding to "very short term" forecasting of solar PV output: (a) AGC (b) Economic dispatch (c) Market Trading (d) Maintenance scheduling (e) Plant expansion planning (f) Power smoothing (g) Real-time dispatch (h) Storage decisions (i) Unit commitment

	Answer any EIGHT (8) questions from Q2-Q11 **[8@10 = 80]**
[Q2]	Different domains of smart grid and their components are listed below. Identify which components belong to which domain and **prepare a list** accordingly. [Some characteristics may be common to more than one domain] **Domains:** Generation, Transmission, Distribution, Customer, Operations, Market, Service Provider **Characteristics:** Account management and controlling operations, Appropriate regulatory policies, Billing and customer complain management, Communication infrastructure, Coordinated operation of generation plants, Customers play a very important role through demand response, Development of power market, Distributed energy resources (DER), Energy-efficient transmission network, Forecasting for renewable generation, Information exchange between the distribution system operators (DSO) and the customers, Information exchange with the consumers or prosumers, Installation and commissioning services, Interact with various service providers, Introducing building or home automation system, Metering, Optimal utilization of the transmission network by system operators' pricing information availability, Real-time information exchange, Real-time monitoring and protection of the transmission network, Recording, Remote coordination of DERs by distribution system operators (DSO), Substation automation and distribution automation, Wide-area monitoring system (WAMS) enabled by communication technologies, Co-existence of various types of renewable and non-renewable generating technologies
[Q3]	Some of the challenges for implementation of smart grid are listed below. You need to suggest probable ways for overcoming each of those challenges individually from the list of solutions provided. [There can be more than one solution for a given challenge, or similar solutions may be applicable to more than one challenge] **Challenges:** Data security and privacy, Demand response participation, Disturbance identification, harmonic suppression to ensure quality power, Grid reliability, Highly uncertain systems, Implementation of self-healing action, Inadequacy of energy storage systems, Lack of customer awareness and participation, Renewable Energy Integration **Probable solutions:** Accurate RES forecasting and fast acting controllers; Conducting regular awareness programs through media; Development of strong data routing system with secure and private network for reliable protection, control, and communication; Incorporating robust forecasting and fast acting intelligent controllers; Installing firewalls and upgrading cyber security programs to ensure customer data privacy; Keep user comfort in mind; Material and technology development in energy storage sector; Need fair pricing strategy; Improved design of converters, filters, FACTS devices, and controllers; Wide area monitoring system, SCADA, smart metering

[Q4] From the following list, identify which are (A) the benefits, and which are (B) the challenges of integrating renewable energy sources to the power grid.

Benefits OR challenges of RE integration to grid: Accurate metering; Active and reactive power control; Aggravated frequency regulation; Aggravated voltage regulation; Augmenting storage systems; Deferments of investments in infrastructure; Designing Fault Ride-Through (FRT) and Voltage Ride-Through (VRT) capabilities; Ensuring cyber-physical security; Environmental friendliness; Improved availability; Increased short circuit levels; Interfacing issues for seamless grid-integration; Introduction of harmonics; Introduction of uncertainty; Maintaining system stability; Network congestion; Protection system design; Reduced electricity price; Reduced lead time; Reduction in Transmission and Distribution (T&D) losses; Response flexibility; Supply reliability; Uncontrolled variability; Utilization of local resources; Voltage and current transients; Voltage support and improved quality of power supply; Voltage unbalance

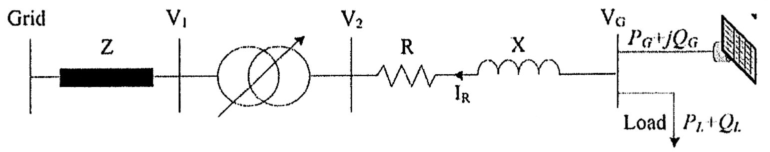
[Q5] Automatic Generation Control (AGC) is essential in power system operation for ensuring frequency stability. From the following jumbled list below, complete the Table by identifying the type of AGC component used for a given type of power source. [A given type of power source can have multiple AGC components]

<table>
<tr><th>Type of Power Source</th><th>Type of AGC components used</th></tr>
<tr><td>Conventional rotating generators</td><td rowspan="5">Capacitance storage units (CES) with FACTS devices; Converters with active and reactive power support capabilities; Dynamic demand response and flexible loads; GPS for time-synchronization of PMU measurements; Intelligent and adaptive controllers such as GA, ANN, Fuzzy; Load-frequency control loops; PID controllers; Pitch angle control; PMU for tie-line power measurements; Rotor speed control; Soft computing techniques; Soft computing techniques for MPPT; Speed and frequency sensor; Virtual inertia controllers</td></tr>
<tr><td>Solar PV systems</td></tr>
<tr><td>Wind energy conversion systems</td></tr>
<tr><td>Energy storage systems</td></tr>
<tr><td>Smart grid</td></tr>
</table>

[Q6] A section of a renewable energy microgrid connected to main grid is shown in the following figure. The line impedance is $Z = 2 + j3\ \Omega$. Generator bus voltage is $V_G = 415$ V. Solar PV generated power, and load consumption over the day are given in the following table. Calculate the voltage regulation at transformer secondary and plot it with respect to different hours of the day. [Use graph paper with proper scale and axes labels].

Hour	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00
S_G (kVA)	4 + j3	6 + j6	10 + j6	15 + j8	24 + j12	24 + j12	14 + j8	0
S_L (kVA)	2 + j6	10 + j5	12 + j10	10 + j6	14 + j10	16 + j12	20 + j16	24 + j20

[Hint: Voltage regulation $\Delta V_G = V_G - V_2 = \frac{(P_G - P_L)R}{V_G} + \frac{(Q_G - Q_L)X}{V_G}$]



[Q7] Utilities make use of following smart grid installations to improve the response of Outage Management System (OMS):
(A) AMI (Advanced Metering Infrastructure) (B) FCI (Faulted Circuit Indicator) (C) DA (Distribution Automation).

Complete the following Table to indicate features of the above three individual components from the jumbled list provided below. Add rows below if you need. [Some features may be common to all three]

List of Features: Advances in communications have enabled the applicability of this component; Automated monitoring of these devices can speed-up fault detection and location while eliminating the tedious task of driving along power lines to look for which of these devices have tripped; Because all of the affected devices issue a last gasp message when an outage occurs, utilities get timely outage notification and an accurate picture of outage location; By integrating communication capability with these devices, the OMS can perform this task of inspection from a central location; Intelligent switches, reclosers, sectionalizes, capacitor banks and transformers can be actively monitored and remotely operated from substations and utilities' data centers; Restoration notifications from these devices can help avoid dispatch of line crews for restoration verification; These devices can automatically isolate faults and reconfigure feeders to restore electricity with no operator intervention, reducing outage duration from hours to minutes; These devices with last gasp capabilities alert the OMS the moment an outage occurs; This device can assist outage detection and isolation; Traditionally, monitoring of these devices involved a lineman drive along a distribution feeder, visually inspecting each of these devices along the line to see if it has tripped; When time-stamped, they also help utilities accurately calculate Customer Average Interruption Duration Index (CAIDI); With the help of this facility, utilities can quickly and automatically pinpoint distribution network faults, reducing the scope and duration of outages and protecting critical assets

Smart Grid installations assisting OMS		
AMI	**AMI**	**AMI**

[Q8] Two major enabling components of Advanced Metering Infrastructure (AMI) in smart grid are Smart Meter and Meter Data Management (MDM) system. The following jumbled list contains components and functions of AMI and MDM in smart grid. **Draw a suitable flowchart** showing interrelation between these functions. Processes in the flowchart must be positioned sequentially demonstrating the data flow direction and interconnected with properly directed arrows. [*There may be multiple connections between different blocks*]

Abnormal Event Detected?	Alarm generation	Bill generation	Cyber threat	Data archiving
	Data validation	Demand response	EMS	Electric load
WAN	HAN	Load forecast	NAN	Reporting
Meter Data Management	Net metering	Tamper detection	OMS	Pre-paid metering
Meter Data Aggregator	Smart energy meter	Meter maintenance	START	STOP

[Q9] For offering benefits to grid-scale storage, energy storage systems (ESS) in smart grid should meet certain performance requirements. The following list contains the desired performance requirements of ESS to be beneficial to grid-scale storage. Identify which are (A) the benefits, and which are (B) the requirements of ESS for use in smart grid, and write them in two separate columns with proper column headings in a **Tabular form**. [*There are some dummy entries*]

Jumbled list of Benefits OR Requirements of ESS in Smart grid:
Avoiding dispatch for high tariff power plants, Balancing RES variability, Black-start services, Capacity investment deferral, communication ability, component of SCADA, congestion management, cost-effectiveness, easy scale-up potential, emergency support, environmentally benign, frequency support, grid compatibility, help in meter data management (MDM), high energy density, large capacity, long cycle life, outage management, postponement in T&D infrastructure upgradation, ramping flexibility, rapid charge/discharge rates, reduced curtailment of RE generation, increased reliability, improved safety, stable operation and performance, system balancing, tamper proofing, voltage support

[Q10] The following table shows actual daily load demand (MW) data of West Bengal on 30th April 2024, along with predicted load demand following ARIMA model, and ANN model. Calculate the Mean Absolute Error (MAE), and Root Mean Square Error (RMSE) in prediction using the two methods and comment on which model is better.

Hour	Actual	ARIMA	ANN
0	9038	8776	8604
1	8673	8777	8760
2	8433	8180	8694
3	8259	8127	8606
4	8046	7748	7933
5	7960	8382	8127
6	7834	8234	7795
7	8041	8459	7864
8	8295	7930	8336
9	8426	8249	8729
10	8859	8558	8735
11	9492	9454	9264
12	9766	10069	10088
13	9750	9204	10004
14	9845	9530	10347
15	9635	10184	9760
16	9367	9685	9264
17	9162	8933	9528
18	9730	10207	10255
19	9908	9621	10166
20	9804	10196	10108
21	9783	9744	9910
22	9742	10317	9284
23	9801	9438	9938

Hint:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|\hat{X}_i - X_i\right| \quad , \quad RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\hat{X}_i - X_i\right)^2}$$

[Q11] Match the smart grid technologies (Column A) with their definitions (Column B)

(A)Technology	(B) Definition
Smart Grid (SG)	In smart grid, it is a strategy where electricity users adjust their consumption in response to tariff rates, helping to balance supply and demand and improve grid stability
Automatic Generation Control (AGC)	It ensures the balance between electricity generation and consumption by automatically adjusting the active power output of generators to maintain frequency stability and grid reliability
Load Frequency Control (LFC)	It is a central data repository system that supports storage, archiving, retrieval & analysis of smart meter data and various other MIS along with validation & verification algorithms
Energy Management System (EMS)	It is a collection of applications used by the Distribution Network Operators (DNO) to monitor, control and optimize the performance of the distribution system and is an attempt to manage its complexity
Distribution Management System (DMS)	It is a computer system that comprises a software platform providing essential support services for smart grid, and a set of applications providing the functionalities necessary for the efficient operation of power generation, transmission and utilization facilities to ensure security of energy supply at minimum cost
Demand Side Management (DSM)	It is a software solution for smart grid that helps utilities efficiently manage power outages by integrating with various systems to detect, locate, prioritize, and restore power
Meter Data Management (MDM)	It is a system consisting of modern electronic-digital hardware and software, that can measure, collect, transfer and analyze energy usage in real time and share this information with different stakeholders as needed
Outage Management System (OMS)	It is an advanced measurement technology that consists of advanced information tools and infrastructure which facilitates operation of the complex smart grid network by collecting and processing data. It enhances grid monitoring, control, and optimization by using real-time data from Phasor Measurement Units (PMUs)
Wide Area Monitoring System (WAMS)	It is crucial for maintaining a stable and reliable electricity supply in smart grid by balancing generation and demand, ensuring a stable frequency, and enabling efficient electricity exchanges
Advanced Metering Infrastructure (AMI)	It is equipped with Automation, Communication and IT systems that can monitor power flows from generation to consumption and control the power flow or curtail the load to match generation in real time or near real time

-------------------------------- End of Question paper ____________________