Best Practices in Power System Operation and Grid Management

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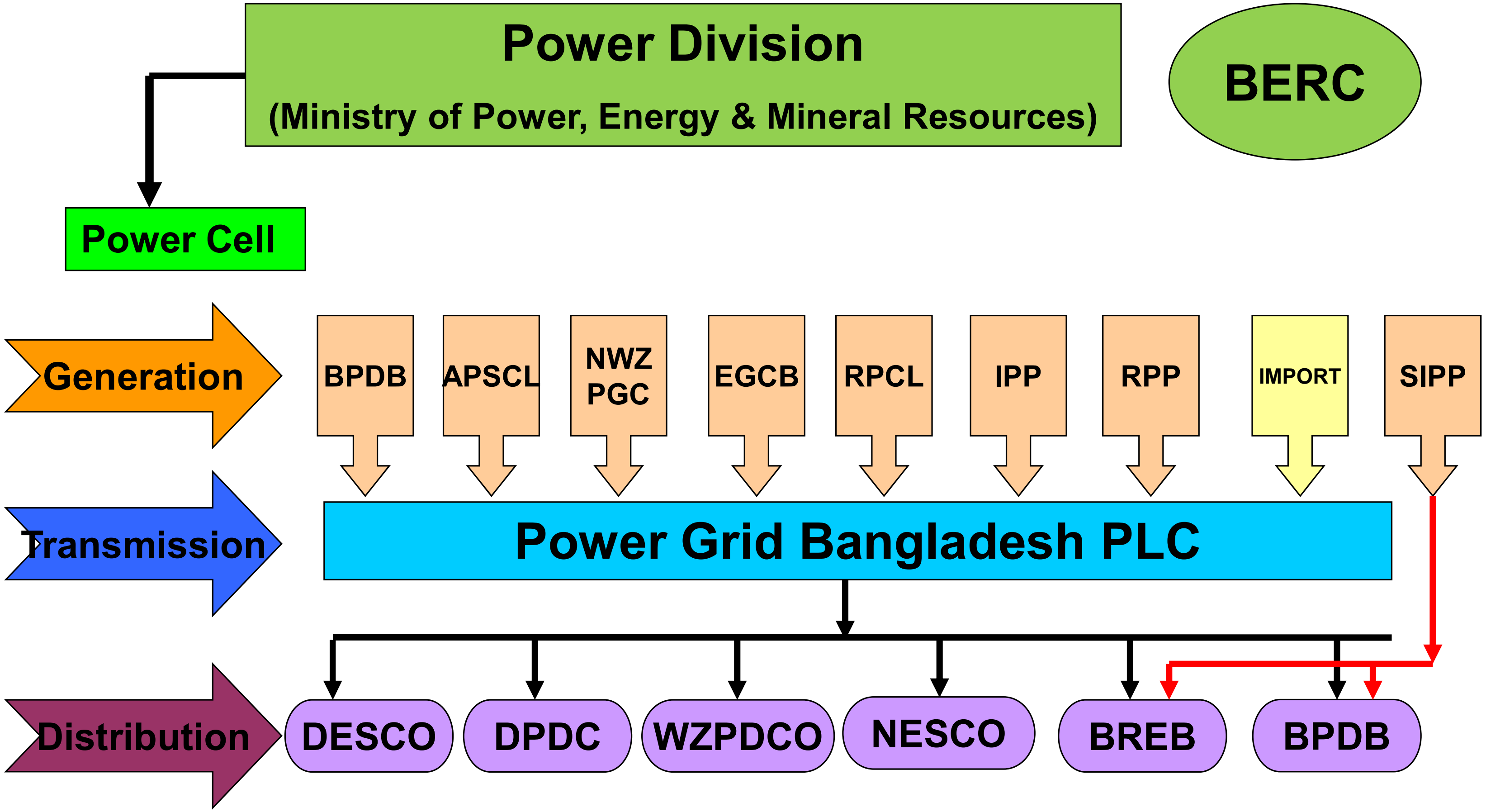
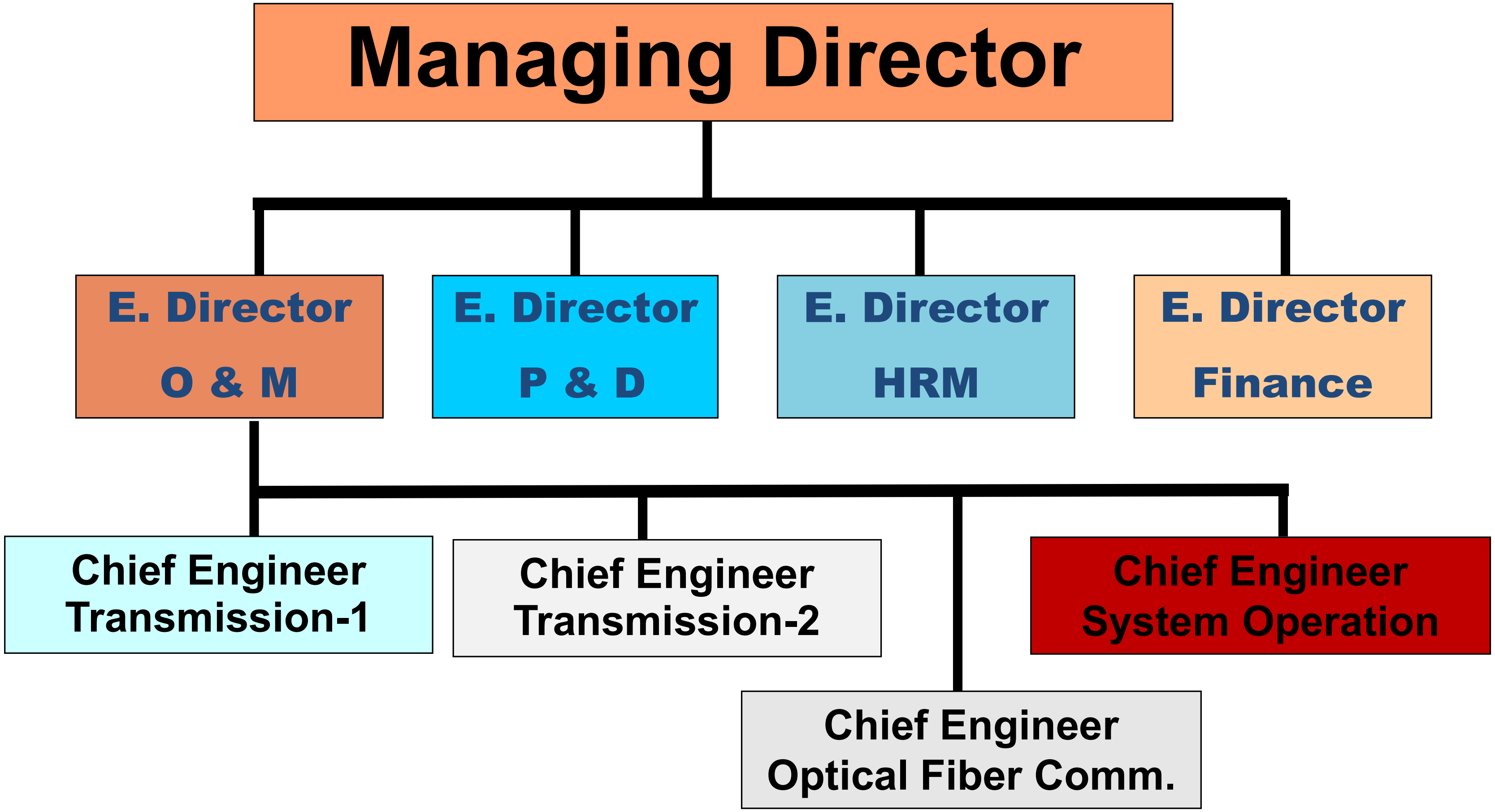
Agenda

- Overview of Bangladesh Power System
- Grid Operation & Management
- Current Challenges in Modern Grids
- Real-Time Monitoring & Control
- Renewable Integration & Flexibility
- Reliability & Contingency Planning
- Cybersecurity & Risk Management
- Asset Management & Predictive Maintenance

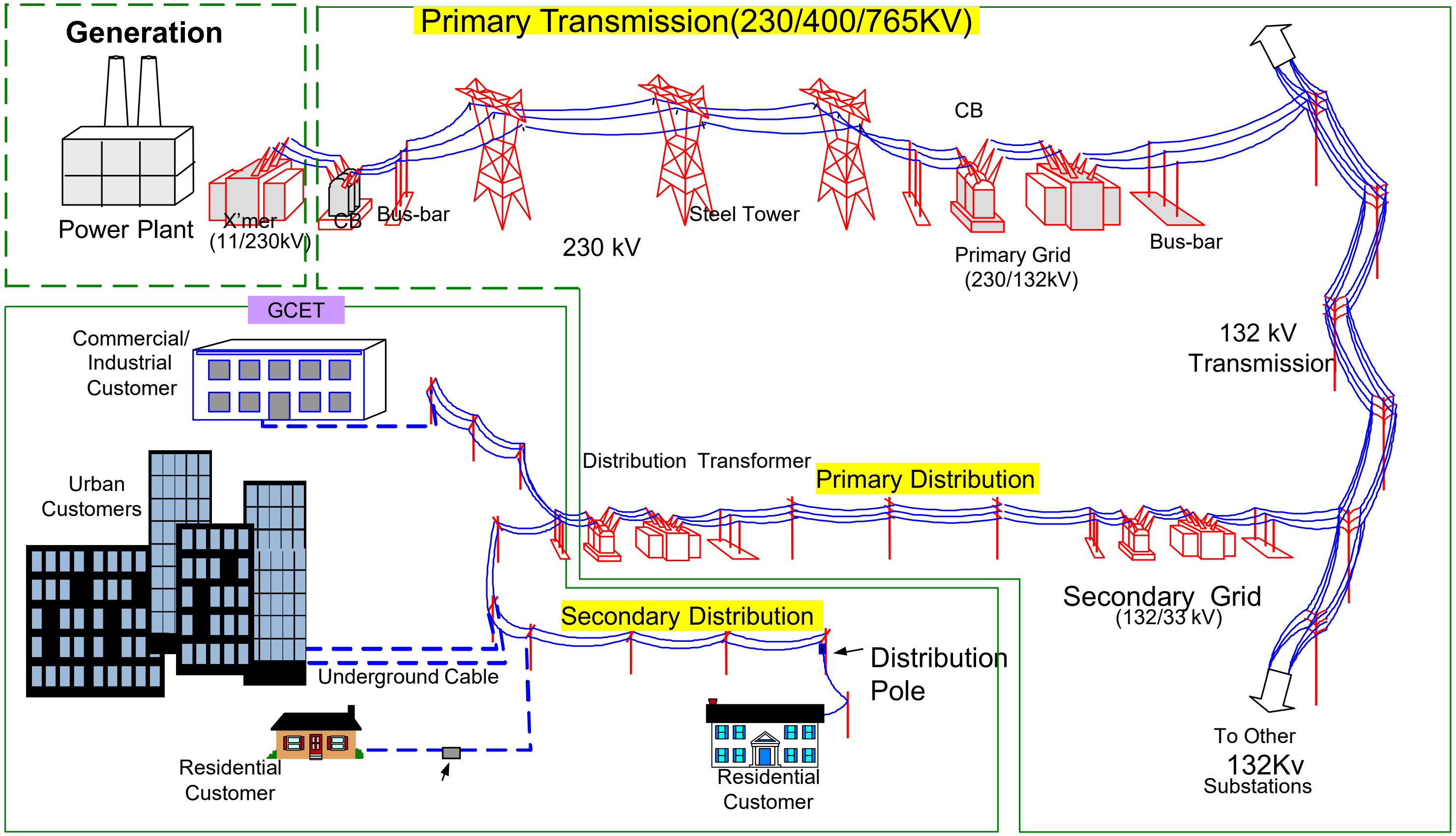
Institutional Framework
Bangladesh Power Sector



Power Grid Bangladesh PLC
Organogram



POWER SYSTEM COMPONENTS



Generation Overview of Bangladesh

Installed Capacity by Fuel Type:

Fuel Type	No of Plants	Installed MW	(%)
Natural Gas	50	12,472	43%
Furnace Oil	54	5,641	19%
Diesel	5	768	3%
Coal	8	6,273	22%
Hydro	1	230	1%
Solar & Wind (Off-grid)	17	829	3%
Import	-	2,696	9%
Total	135	28,909	100%

Upcoming NPP: 2x1200MW

Substation & Transmission Line of Power Grid

- **Transmission Voltage :132 kV - 400 kV**
  - **Power Grid Bangladesh PLC:**

    Only entity for High Voltage Transmission Operation

Transmission Line **(Up to December,2025)**

400 kV	**: 3087.0 ckt. Km (other entity-27.8 ckt.Km)**	
230 kV	**: 5023.79 ckt. Km (other entity-27.3 ckt.Km)**	
132 kV	**: 9150.07 ckt. km (other entity-368.68 ckt.Km)**	
Total	**: 17685.27 ckt. Km**	

Grid Sub Station Capacity **(Up to December,2025)**

HVDC BtB Station	**: 2x500 MW**
400 kV	**: 20850 MVA**
230 kV	**: 24785 MVA**
132 kV	**: 40097.9 MVA**
Over all Capacity	**: 85732.9 MVA**

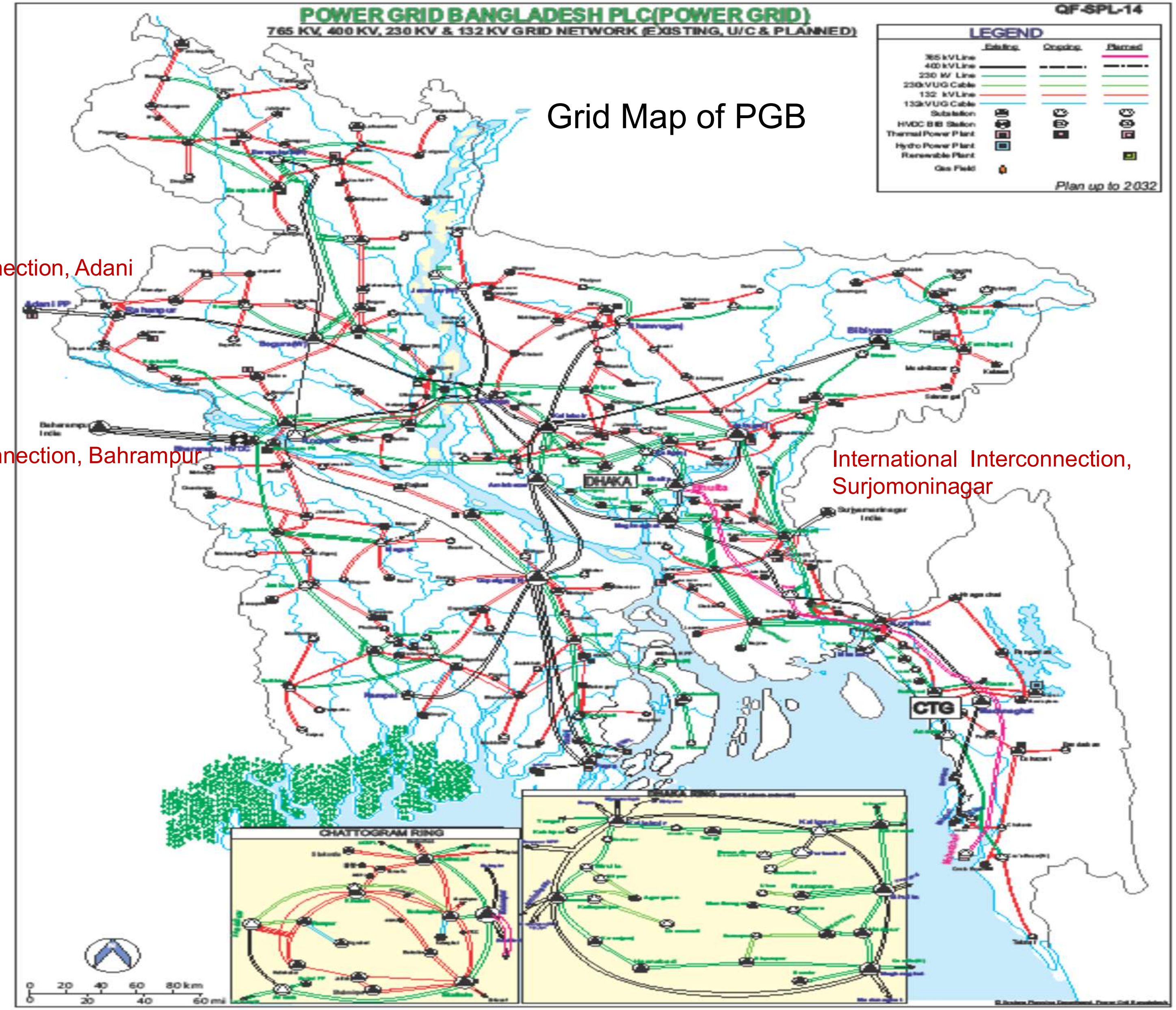
Dispatch capacity at 33kV : 37537.11 MW

Grid Map of PGB

International Interconnection, Adani

International Interconnection, Bahrampur

International Interconnection, Surjomoninagar



Power System Operation & Grid Management

Operation of the interconnected power system is coordinated through National Load Dispatch Centre in collaboration with the Generating Stations, Grid Substations and Distribution utilities. Prompt action by the system operator during minute-to-minute operations as well as system emergency is vital for the reliability of power system.

Core Functions and Importance in the Energy Transition are-

- ❖ Real-time balancing of supply and demand (frequency & voltage control), NLDC Plays vital role.
- ❖ Transmission, distribution, and DER integration, System Planning play's vital role.
- ❖ Shift to smart grids with renewables, storage and digital controls, System Planning play's vital role.

Key Role of NLDC

The National Load Dispatch Centre (NLDC) conducts day-ahead load forecasting to estimate hourly demand over a 24-hour horizon. Based on this forecast, it performs unit commitment and economic dispatch to optimally schedule generating units—determining their on/off status and output levels across time intervals. The objective is to minimize operational cost while maintaining system reliability and meeting all operational constraints (e.g., reserves, ramp limits, and transmission limits). The end-to-end process, from forecasting to dispatch implementation, comprises five key stages.

- **load prediction,**
- **resource optimization,**
- **security assessment,**
- **scheduling, and**
- **real-time execution.**

Network Operator Performs

- System Frequency Monitoring & Control
- Voltage Monitoring & Control
- Line Load Monitoring & Control
- Emergency and Planned Outage
- Restoration
- Cross Border Import Schedule Implementation
- Economic Dispatch
- Load Management
- Reporting

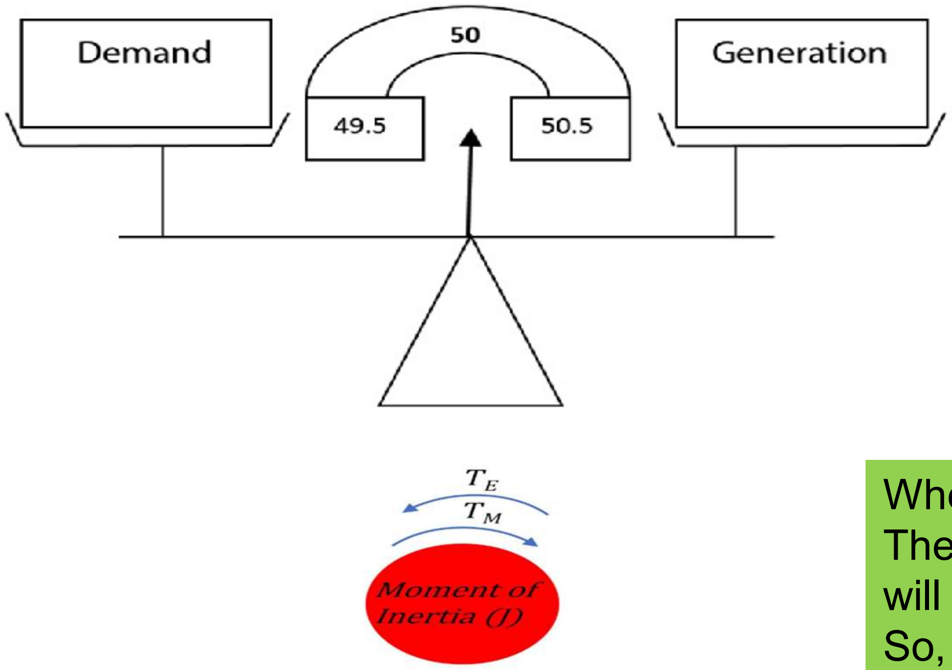
Security Control

Security control is a complex decision-making process that ensures reliable power system operation under all conditions by initiating appropriate control actions.

The operation is governed by three key constraints:

- **Operating Constraints:** Limits on system variables and equipment (e.g., voltage levels, generator loading, transmission thermal limits, transformer tap positions).
- **Load Constraints:** Total customer power demand that must be satisfied.
- **Security Constraints:** Requirements to maintain adequate reserve margins in generation and transmission.

System Frequency Monitoring and Control
(Prerequisite for Frequency as well as System Stability)



$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_a = P_m - P_e$$

When Load Gen is Balanced, i.e, P_a= 0, then w = const
The moment P_a = 0, Frequency will be constant and will remain const. until P_a remains 0.
So, Load Gen Balance may occur at any possible frequency within operating range.

System Frequency Response

$$\frac{2H}{f_0} \cdot \frac{df}{dt} = \Delta P$$

- Where

  df/dt = Rate of change of frequency

  H=The system inertia constant is the kinetic energy stored in the system per MVA; (Typically 3 to 10 secs)

  f_0= System nominal frequency

  ΔP= Change in active power in pu.

Frequency Response: Example

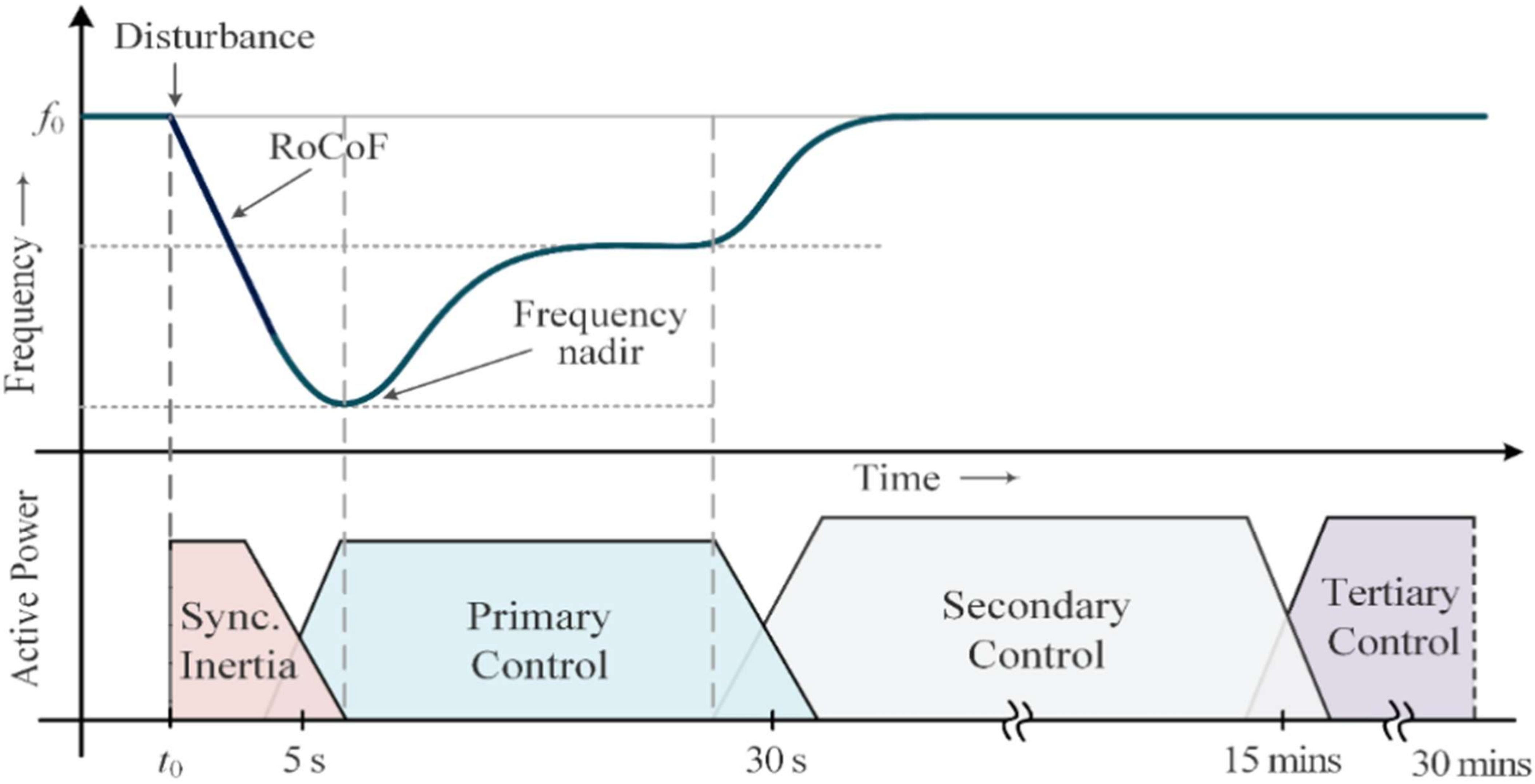
- Assuming inertia constant as 8 seconds, the rate of change of frequency for a loss of 1500 MW in the system size of 60,000 MW operating at 50 Hz can be computed as below:

- P_L = 60000
- P_G = 60000-1500 = 58500 MW
- ΔP = 1500/58500 = 0.0256
- f_o = 50
- H = 8

- Df/dt = 0.0256 x{ 50/(2x8)}= 0.080 Hz/second

Frequency Control

Level of Frequency Control	Description	Response	Functions	Mode of operation
Primary	Autonomous and automatic	MW/Sec	Governor Response, Load damping, Fr responsive load control	Auto
Secondary	Centrally coordinated actions to return fr to its scheduled level	MW/Min	AGC -Implementation is underway in Bangladesh - Fr is allowed to float in a range now	Regulation
Tertiary	Centrally coordinated actions to dispatch generation/load to a new operation point while maintaining balance	MW/Min	Economic Load Despatch	-Ramping, -Load following


Disturbance
f_0
RoCoF
Frequency
Frequency nadir
Time
Active Power
Sync. Inertia
Primary Control
Secondary Control
Tertiary Control
t_0
5 s
30 s
15 mins
30 mins

Primary Mode of Control

Primary Control (Frequency Control): First-level, fast-acting control that stabilizes system frequency immediately after a disturbance.

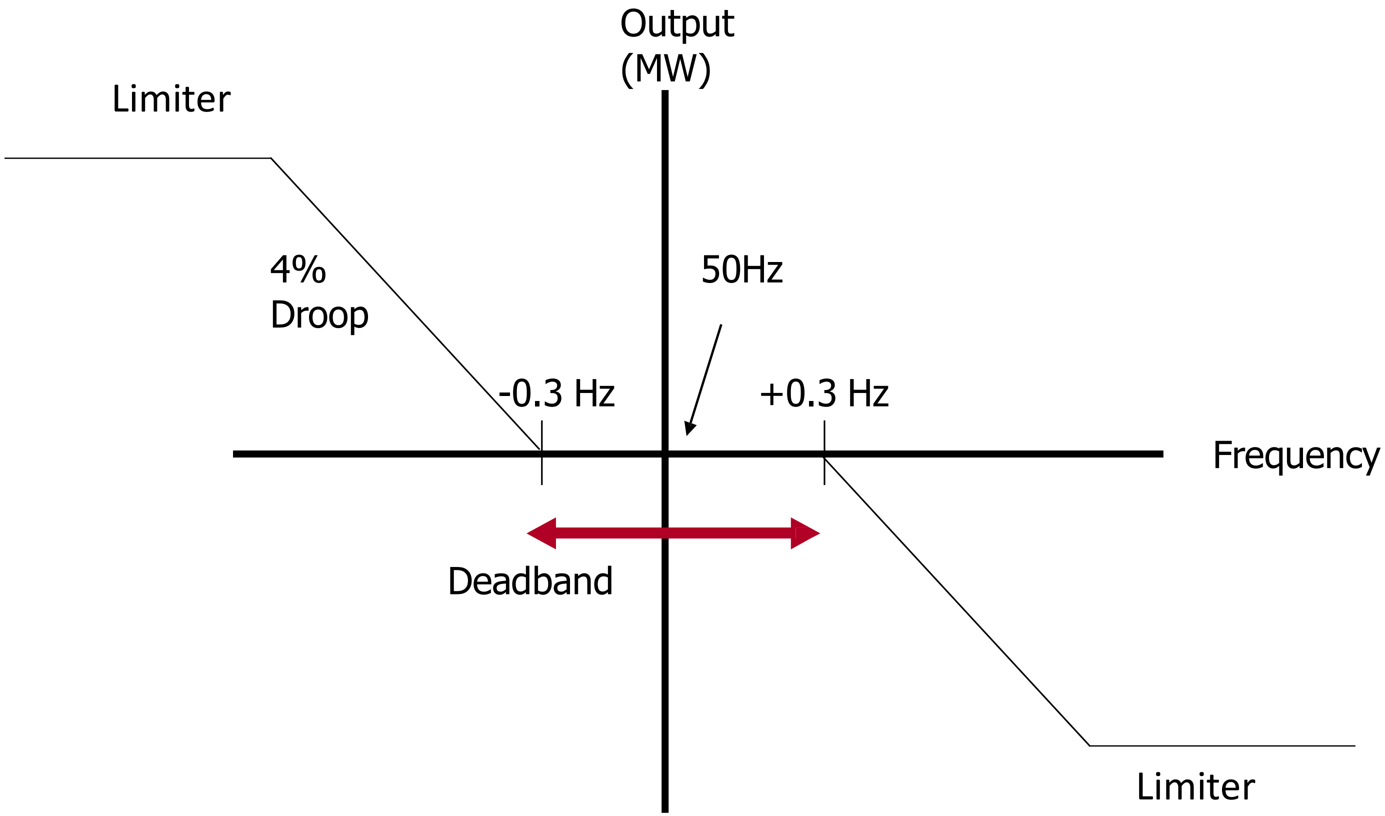
- **FGMO (Free Governor Mode of Operation):** Generators operate with active governor response, enabling autonomous adjustment of mechanical input based on frequency deviation (Δf).
- **Droop Characteristic:** Output power variation is proportional to frequency deviation as per predefined governor droop settings (typically 3–5%).
- **Decentralized Response:** No central command required; all FGMO-enabled units participate simultaneously in frequency regulation.
- **Dynamic Action:**
  - •Under-frequency (generation deficit) → Increase in turbine input → Increase in active power output.
  - •Over-frequency (generation surplus) → Decrease in turbine input → Reduction in active power output.

Objective: Arrest frequency deviation, ensure load-generation balance, and enhance system stability in the initial seconds following a disturbance.

FGMO Parameters

Free Governor Mode of Operation operates on three parameters which are

- **Droop setting,**
- **Dead band and**
- **Limiter**



Secondary Mode of Control

Secondary control in power system operation is implemented through Automatic Generation Control (AGC), which acts after primary (governor/FGMO) response to restore system frequency and scheduled inter-area power exchanges to their nominal values

- **AGC Control Basis :** AGC system operates automatically on **Area Control Error (ACE)**, which combines frequency deviation and tie-line power deviation.
- **Setpoint Adjustment:** It manually modifies generator reference setpoints (MW output) to correct deviations of frequency.
- **Centralized Control:** Control signals are generated at the control center (e.g., NLDC) and sent to selected generators.
- **Time Response:** Slower than primary control; typically acts over **seconds to minutes**.
- **Objectives:**
    - Restore system frequency to nominal frequency(e.g., 50 Hz).
    - Maintain scheduled inter-area power flows.
    - Minimize ACE and ensure system balance.

AGC, Cont.

The key to the whole control operation is the comparison of Area Control Error(ACE) and Station Control Error(SCE)

$$ACE = P_a - P_s - B_f(f_a - f_s)$$

- P_a – Actual Net Interchange
- P_s – Scheduled Net Interchange
- B_f- Frequency Bias Setting
- f_a – Actual Frequency
- f_s – Scheduled Frequency(50Hz)

Tertiary Mode of Operation

It’s the highest-level control layer responsible for optimal system operation and reserve management after primary (FGMO) and secondary (AGC) actions. Typically executed by system operators at control centers (e.g., NLDC) based on system conditions and forecasts.

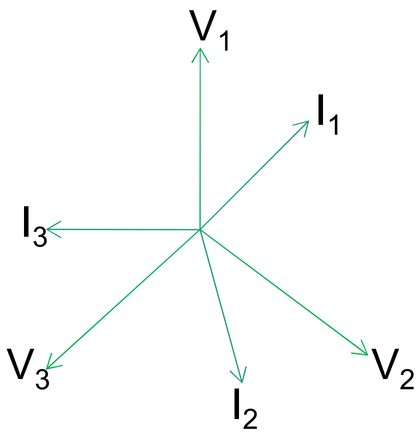
- **Time Frame:** Acts over **minutes to hours** (and day-ahead planning horizon).
- **Restore and replenish spinning reserves** used during primary/secondary control
- **Key Functions:**
  - Re-dispatch generation to achieve **economic operation (cost minimization)**
  - Manage **unit commitment and de-commitment** decisions
  - Handle **congestion management** and transmission constraints
- **Control Actions:** Adjustment of generator schedules, interchange transactions, implent under frequency load rejection and reserve allocation.

- **Objective:** Ensure long-term system security, reliability, and economic efficiency while maintaining adequate reserve margins.

Frequency Protection

- Setting of Under frequency Relay adopted in different substations for automatic load rejection.
- Setting of Rate of Change of Frequency adopted in different substations for automatic load rejection
- Frequency Protection settings adopted in Generating Stations as per limit of Grid Code

Voltage Monitoring and Control



- By controlling Reactive Power of Generators
- Switching of Capacitor Bank.
- Transformer tap position change.
- Load Rejection Scheme.

Q sources and sinks

S/N	Sources (Q- Generation)	Sinks (Q – Absorption)
1	Gen. Over excited	Gen. Under excited
2	Transmission Lines - charging	Transmission Lines - series reactance drop
3	Shunt Capacitors	Shunt Reactors
4	Static Var Compensators (Q –gen mode)	Static Var Compensators (Q – absorb mode)
5	Series Capacitors (C_{se})	-
6	Synchronous Condenser over excited	Synchronous Condenser under excited
7	Loads -Capacitive	Loads - Inductive

Reactive power loss in PS

- Inductance (L) is associated with generator, transformer, line, motor, reactor leading to x_g, x_{tr}, x_l, x_m, x_r reactances respectively.
- The capacitance associated with PS elements is not so significant. Hence $Q_L > Q_C$. The reactive power absorption is > reactive power generation under nominal loading conditions.
- Due to $I.X_L$ there will be voltage drop in the power system element
- The resultant I^2X_L needs to be compensated, if not the voltage profile decreases towards the loads.

Line Loading - voltage profile

- During line charged condition $Q_C = V^2 \omega C$ is injected for every km of line where C is the Capacitance per km.
- Due to this Ferranti effect the line potential rises towards the receiving end (RE).
- When the loading on the line is raised $Q_L = I^2 X_L$ is absorbed by every km length of line by the series inductance of the line (X_L/km) due to flow of current I.
- When $Q_C = Q_L$, the loading is called Surge Impedance Loading (SIL) of the line
- If the loading increases beyond SIL the $Q_L > Q_C$ hence the voltage profile along the length of the line decreases towards the Receiving End.
- The decrease in voltage profile will be more pronounced during loading conditions >> SIL.

SYSTEM PERFORMANCE

Electricity Grid Code 2019 Reference

The Transmission System frequency shall normally be 50.0 Hz and shall normally be controlled in the range 49.5 – 50.5 Hz (50 Hz ± 1%). The User shall however be subject to the grid discipline directed by the Commission.

- Voltage variation on the Transmission System shall normally be ±5% for 400 kV, ±6% for 230 kV & 132 kV bus during normal operations and ±10% at 400 kV, +10/-15% for 230 kV, 132 kV bus during emergencies in accordance with the provisions of Planning and Security Standards for Transmission System.

Line Load Monitoring and Control

Transmission Line Load Monitoring and Control ensures safe and efficient power flow by continuously observing and regulating transmission line loading to prevent overload and maintain system stability.

Key points:

Real-time monitoring: Current, voltage, and power flow via SCADA/EMS

Thermal control: Keeps loading within conductor limits

Dynamic Line Rating: Adjusts capacity based on weather conditions

Congestion control: Re-dispatching generation or switching network topology to relieve overloaded lines

Protection: Selective tripping during faults.

Outages

- Before outages-> Contingency Analysis
- Plant shutdown- > Additional generations to bring in service or Load Shed.
- Line shutdown- > Security to be ensured after shut down
- Transformer shutdown-> Load rejected therefore frequency to be controlled.
- HVDC Valve Hall shutdown-> About 500MW of power injection to grid become zero so extra generation planning is required.

Restoration

- Full network restoration after blackout-> Blackout Restoration Procedure.
- Partial network restoration- Based on contingency, controlling of voltage and frequency is a challenge.
- S/S or line restoration.

Power import schedule implementation

- 24 Hrs monitoring of power schedule published on website by NLDC India.
- Code exchange with NLDC India and Bheramara for any change in power flow.
- 24 Hrs communication with NLDC India and Power Trading Corporation(PTC) India for any emergency or planned shutdown which may affect power flow between India and Bangladesh.

IMPLEMENTATION AND OPERATION OF THE GRID CODE

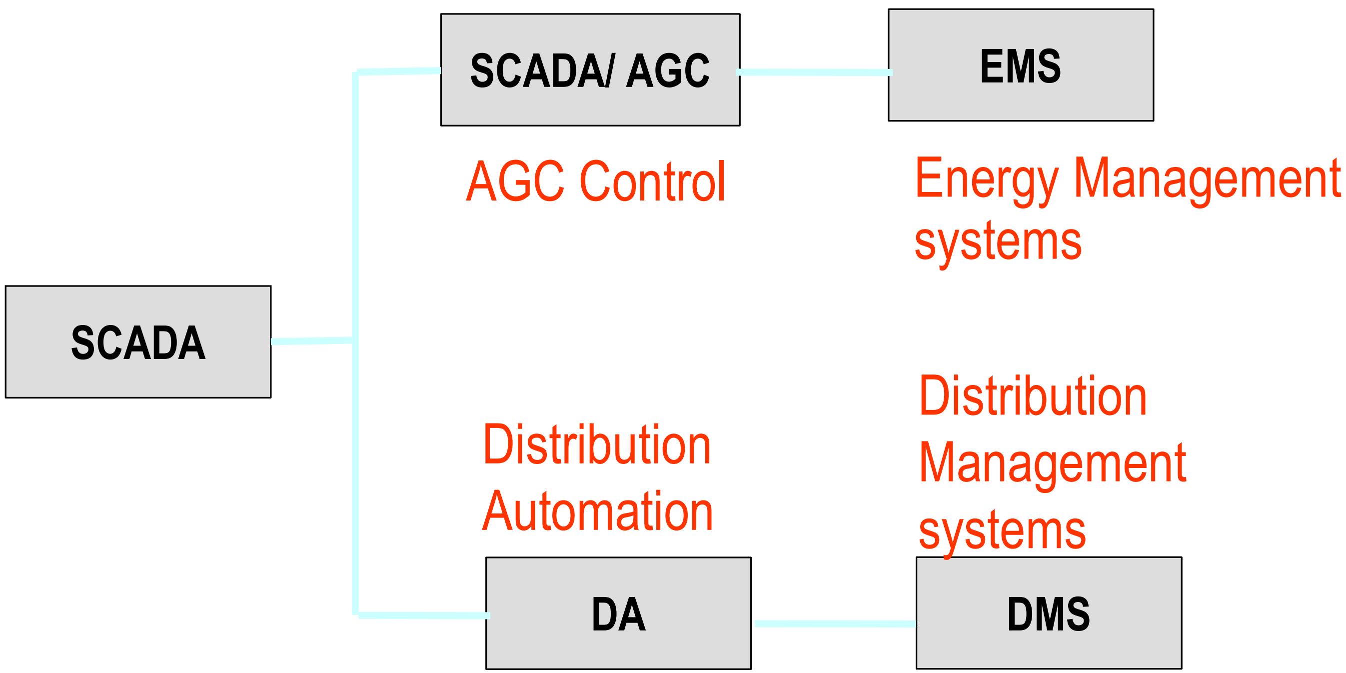
The Licensee has the duty to implement the Grid Code. All Users are required to comply with the Grid Code that will be enforced by the Licensee. Users must provide the Licensee reasonable rights of access, service and facilities necessary to discharge its responsibilities in the Users' premises and to comply with instructions Electricity Grid Code 2012 issued by the Licensee, reasonably required to implement and enforce the Grid Code.

If any User fails to comply with any provision of the Grid Code, it shall inform the Licensee without delay of the reason for its non-compliance and shall remedy its non-compliance promptly. Consistent failure to comply with the Grid Code may lead to Disconnection of the User's plant and/or facilities.

The operation of the Grid Code will be reviewed regularly by the Grid Code Review Panel in accordance with the provisions of the relevant Section of the Grid Code.

SCADA

THE EYES AND EARS OF THE SYSTEM OPERATOR



SCADA / AGC

- Automatic Generation Control
- Economic Dispatch Calculation
- Interchange Transaction Scheduling
- Transaction Evaluation (Area A and Area B)
- Unit Commitment
- Short-Term Load Forecasting

EMS

- Network Configuration/Topology Processor
- State Estimation
- Contingency Analysis
- Three Phase Balanced Operator Power Flow
- Optimal Power Flow
- Dispatcher Training Simulator

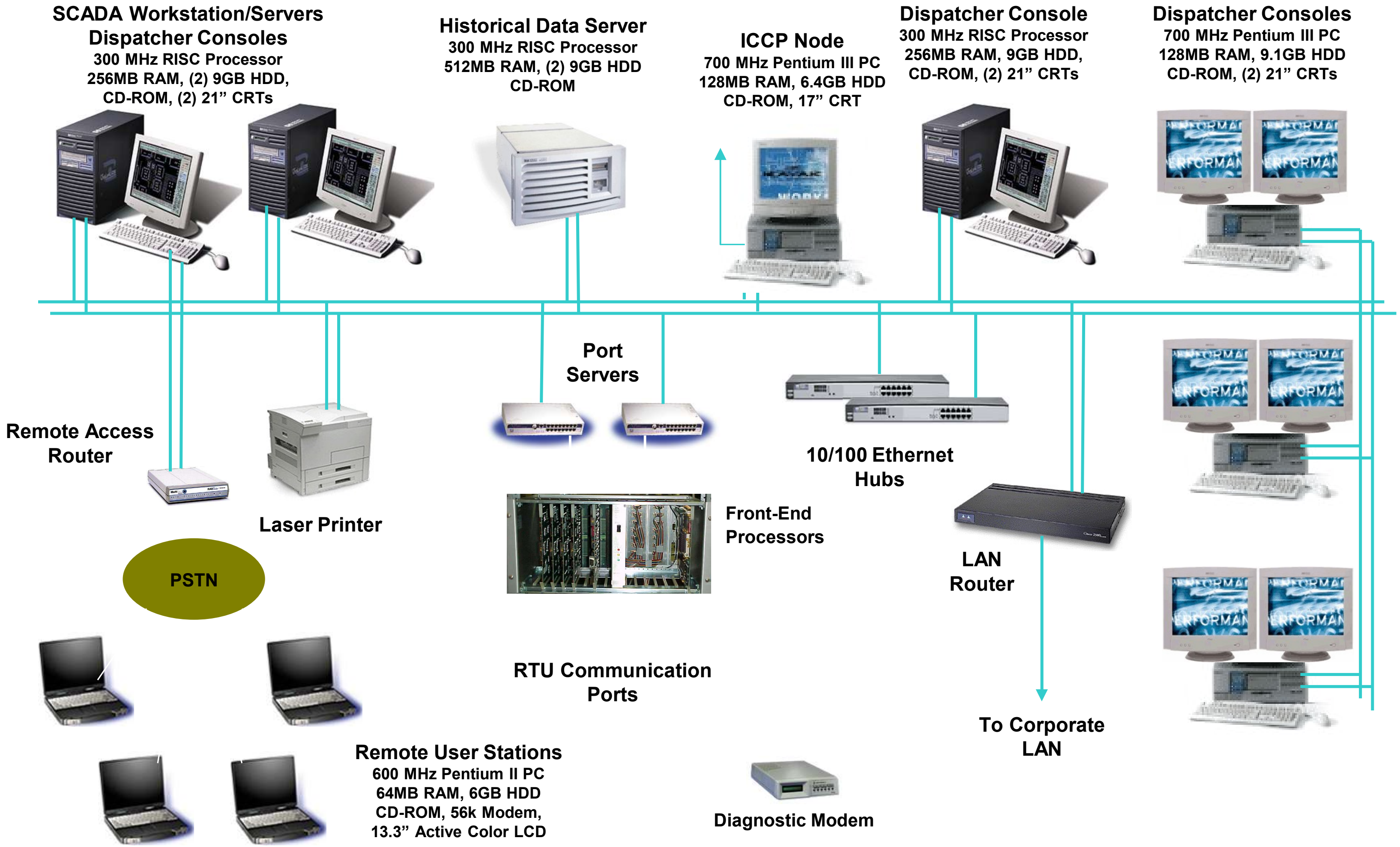
DA

- Voltage Reduction
- Load Management
- Power Factor Control
- Two-Way Distribution Communications
- Short-Term Load Forecasting
- Fault ID/Fault Isolation/Service Restoration
- Interface to Intelligent Electronic Devices (IEDs)

DMS

- Three Phase Unbalanced Operator Power Flow
- Interface To/Integration With Automated Mapping/Facilities Management (AM/FM)
- Interface To Customer Information System (CIS)
- Map Series Graphics
- Trouble Call/Outage Management

SCADA System Overview



FUNCTIONS OF SCADA

- DATA ACQUISITION.
- PROCESSING OF ACQUIRED DATA.
- DATA EXCHANGE.
- LIMIT / STATUS MONITORING & ALARMING.
- NETWORK STATUS PROCESSOR.
- SEQUENCE OF EVENT RECORDING.
- INFORMATION STORAGE & RETRIEVAL.
- SUPERVISORY CONTROL.

FUNCTIONS OF SCADA

- An operator at a master station can cause operations such as the opening and closing of breakers, the starting and stopping of condensers, and the changing of the taps on load-ratio-control transformers.
- The operators can receive an indication that the operation has been completed. All of this can be done over a voice-grade (telephone) communication channel that distinguishes supervisory control from direct wire remote control; the latter requires one direct wire circuit for each controlled device.
- In case of SCADA a single communication line is used for connecting to multiple substations and power plants.

Current Challenges in Modern Grid Operation

Challenges in Navigating the Energy Transition:

- **High Renewable Penetration:** Integration of large-scale **variable renewable energy (VRE)** sources, leading to intermittency and increased **forecasting complexity**
- **Aging Infrastructure and Load Growth:** Existing grid assets facing stress due to **infrastructure aging** and rising demand from **data centers and electric vehicles (EVs)**
- **Climate Resilience Requirements:** Increased exposure to **extreme weather events**, necessitating enhanced grid **resilience and adaptability**
- **Cybersecurity Risks:** Elevated vulnerability to **cyber threats** in highly **digitized and smart grid environments**
- **Distributed Energy Resource (DER) Integration:** Managing **bidirectional power flows** and ensuring grid stability with high penetration of **distributed generation**

Real-Time Monitoring & Control Systems

SCADA, EMS, and Wide-Area Measurement Systems: Power Grid Practice:

- **Advanced SCADA/EMS Deployment:** Implementation of modern **SCADA and Energy Management Systems (EMS)** to provide enhanced **real-time system monitoring, control, and situational awareness**
- **Wide-Area Measurement Systems (WAMS):** Integration of **Phasor Measurement Units (PMUs)** for high-speed, time-synchronized measurements to support **dynamic stability assessment, PMU installed at 11 strategic locations. DFDR installed at all 400kV, 230KV SS & some impotant 132kV ss.**
- **Contingency Analysis:** Execution of **real-time and offline contingency analysis** to evaluate system security under potential fault scenarios
- **Automated Control Functions/Emergency Protection Scheme:** Deployment of **automated control/Emergency Protection schemes** for rapid corrective actions to maintain system stability and reliability

Renewable Integration & Grid Flexibility

Management of Variable Energy Sources:

- **Forecasting and Flexibility Resources:** Implementation of **advanced generation forecasting**, supported by **energy storage systems (ESS)** and **demand response (DR)** to mitigate variability
- **Grid-Forming Inverter Technology:** Deployment of **grid-forming inverters** to provide virtual inertia and enhance **system strength and stability**
- **Ancillary Service Provision:** Utilization of **renewable energy sources and microgrids** for delivering **ancillary services** such as frequency regulation and voltage support
- **Flexible Grid Operations:** Adoption of **operational flexibility measures** to maintain **frequency and voltage stability** under varying generation conditions

Reliability & Contingency Planning

N-1 Criteria and Operational Resilience:

- **Contingency Standards:** Application of **N-1 and N-2 security criteria** to ensure system reliability under single and multiple element outages
- **Frequency and Voltage Control:** Maintenance of system stability through adequate **spinning and non-spinning reserves** for effective **frequency and voltage regulation**
- **Long-Term Resource Adequacy:** Integration of **Integrated Resource Planning (IRP)** to ensure sufficient capacity and infrastructure over the planning horizon
- **Resilience Enhancement:** Strengthening system capability to withstand and recover from **extreme weather events** and **cyber-physical disturbances**

Cybersecurity & Risk Management

- **Defense-in-Depth Strategy:** Implementation of multiple layered security controls to protect systems against diverse cyber and physical threats
- **Internal Network Security Monitoring (INSM):** Continuous monitoring of internal networks with advanced **anomaly detection mechanisms** to identify and respond to suspicious activities
- **Secure Supply Chain Management:** Ensuring cybersecurity compliance across vendors and equipment, along with **controlled and secure remote access services**
- **Regular Security Testing:** Periodic **vulnerability assessments and penetration testing (VAPT)** to evaluate system resilience
- **Zero-Trust Architecture:** Adoption of a **zero-trust security model** for both **Operational Technology (OT)** and **Information Technology (IT)** environments, enforcing strict identity verification and access control

Asset Management & Predictive Maintenance Power Grid Practice:

- **Enterprise Asset Management:** All transmission assets are managed through an integrated **ERP system** to ensure efficient tracking, maintenance, and lifecycle management
- **Thermal Condition Monitoring:** Periodic **infrared thermographic scanning** of substation equipment to detect hotspots and prevent failures
- **Online Condition Monitoring:** Continuous real-time monitoring of **critical equipment** for early fault detection and performance assessment
- **ROW Surveillance and Inspection:** Use of **drone-based inspection** for transmission line Right-of-Way (ROW), enabling real-time data acquisition and **automated defect identification**
- **Maintenance Optimization:** Implementation of **condition-based and predictive maintenance scheduling** to minimize outages and improve reliability
- **Strategic Integration:** Alignment of asset management with overall **grid planning** and **Integrated Resource Planning (IRP)** for long-term system optimization

Thank You

Any Query or Kind

Suggestion?