ATME College of Engineering

21EE72: POWER SYSTEM OPERATION & CONTROL

MODULE – 1:Introduction,SCADA

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CONTENTS

Course Credit Description:

SL.No.	Course Code	Course Type	Course	Teaching Hours /Week	Exam Duration in Hours	Theory Marks	I.A Marks	Total Marks	Credits
1	21EE72	Core	PSOC	4	3	50	50	100	3

Prerequisites:

SL. No.	Course Name	Blooms Level
1	PSA-I	L4
2	SCADA Fundamentals	L2
3	Control System	L3

Duration	Week 1 to 3:
Module 1: Introduction SCADA	**Introduction:** Operating States of Power System, Objectives of Control, Key Concepts of Reliable Operation, Preventive and Emergency Controls, Energy Management Centers. **Supervisory Control and Data acquisition (SCADA):** Introduction, components, application in Power System, basic functions and advantages. Building blocks of SCADA system, components of RTU, communication subsystem, IED functional block diagram. **Classification of SCADA system:** Single master–single remote; Single master–multiple RTU; Multiple master–multiple RTUs; and Single master, multiple sub master, multiple remote. **10 Hours [L2]**

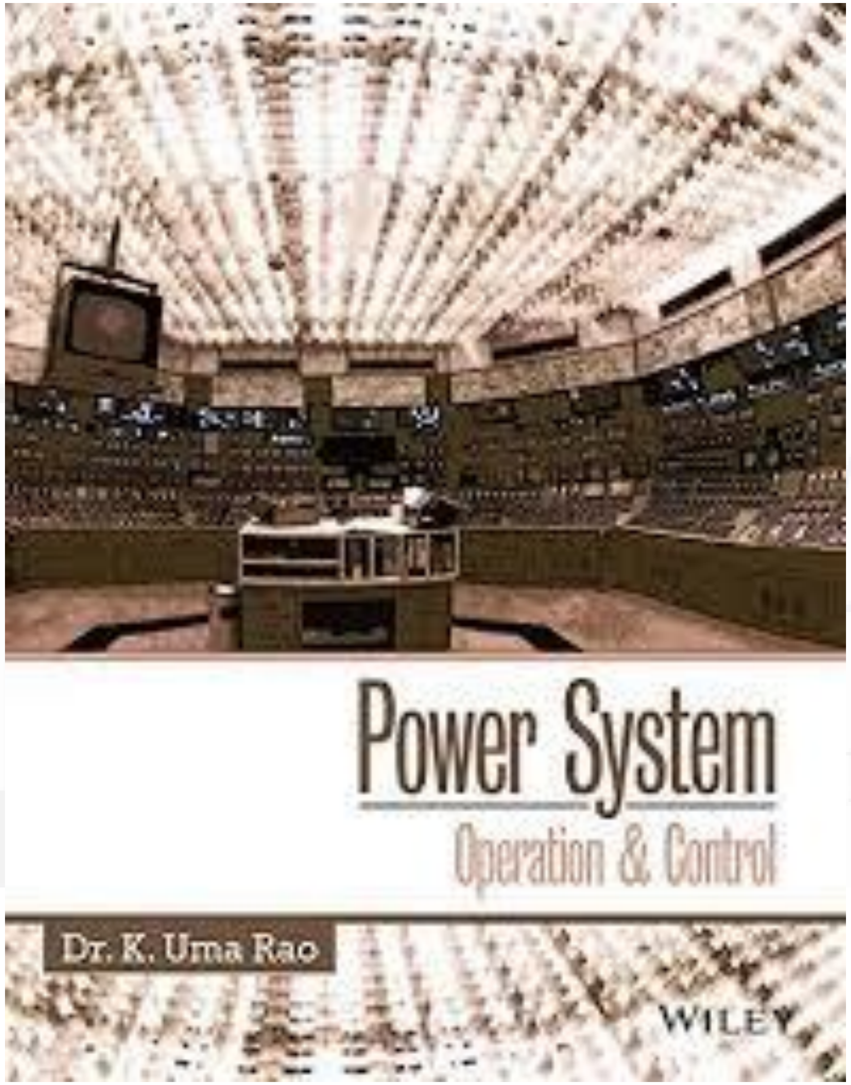
Duration	Week 3 to 5:
Module 2: **AGC**	**Module-2:** **Automatic Generation Control (AGC):** Introduction, Schematic diagram of load frequency and excitation voltage regulators of turbo generators, Load frequency control (Single area case), Turbine speed governing system, Model of speed governing system, Turbine model, Generator load model, Complete block diagram of representation of load frequency control of an isolated power system, Steady state analysis, Control area concept, Proportional plus Integral Controller.[L4]

Learning Resources prescribed by University:

1. **Power System Operation and Control, K. Uma Rao, Wiley, 1st Edition, 2012.**
2. Modern Power System Analysis, D. P. Kothari, McGraw Hill, 4th Edition, 2011.
3. Power Generation Operation and Control, Allen J Wood et al, Wiley, 2nd Edition, 2003.
4. Electric Power Systems, B M Weedy, B J Cory, Wiley. 4th Edition, 2012.

Additional List of URLs, Text Books, Notes, Multimedia Content, etc

1. **Computer-Aided Power System Analysis, G. L. Kusic, CRC Press, 2nd Edition.2010.**
2. **Power System SCADA and Smart Grid, Mini S Thom and John D. McDonald, CRC Press 2015.**
3. **Power System Stability and Control, Kundur, McGraw Hill, 8th Reprint, 2009.**

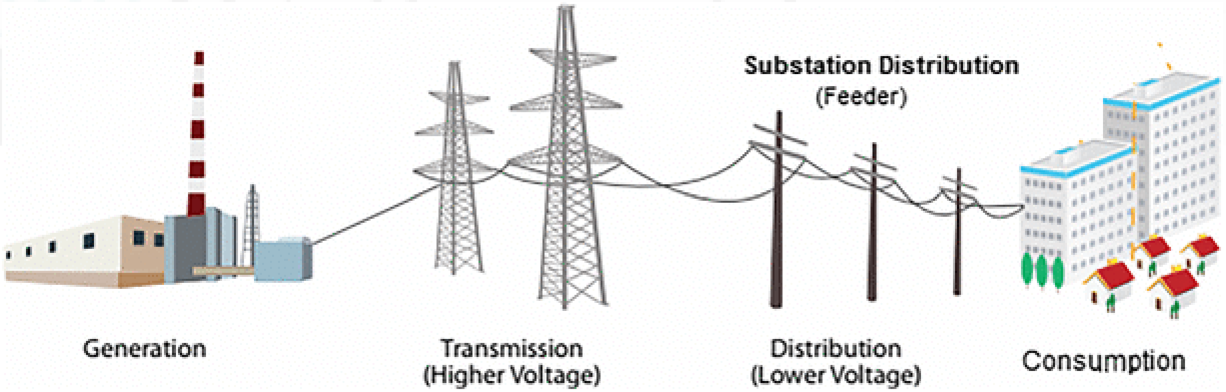

Power System
Operation & Control
Dr. K. Uma Rao
WILEY

Module-1

a) Introduction

b) Supervisory Control and Data Acquisition

c) Classification of SCADA



Introduction

<u>Electricity</u> is a converted form of energy and is used extensively in industrial, commercial, residential and transportation sectors. It can be generated and transmitted in bulk, economically, over long distances.

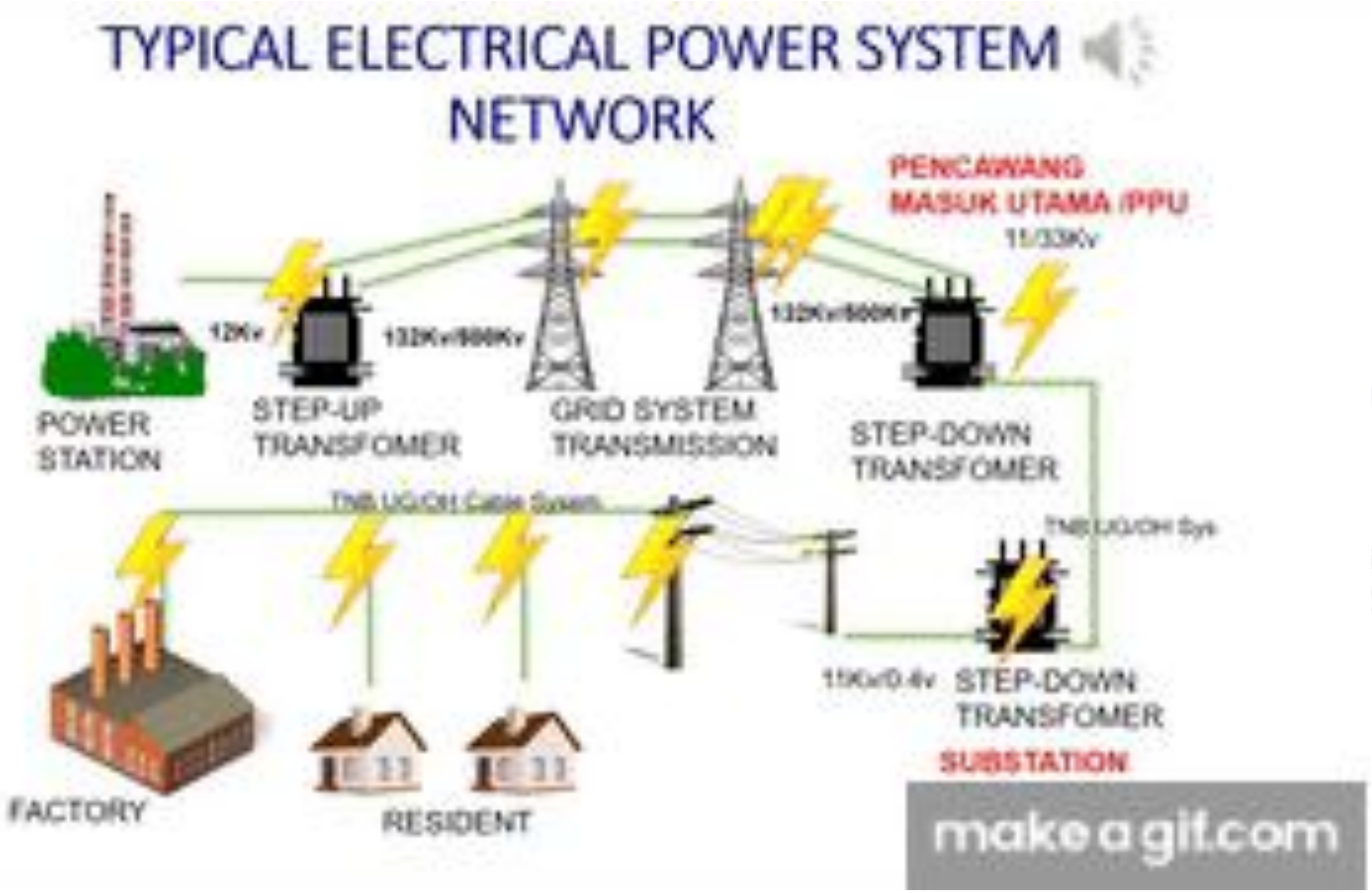
AC systems have become the most popular system for use, over DC, for the following reasons:

1. AC generators are simpler than DC generators.

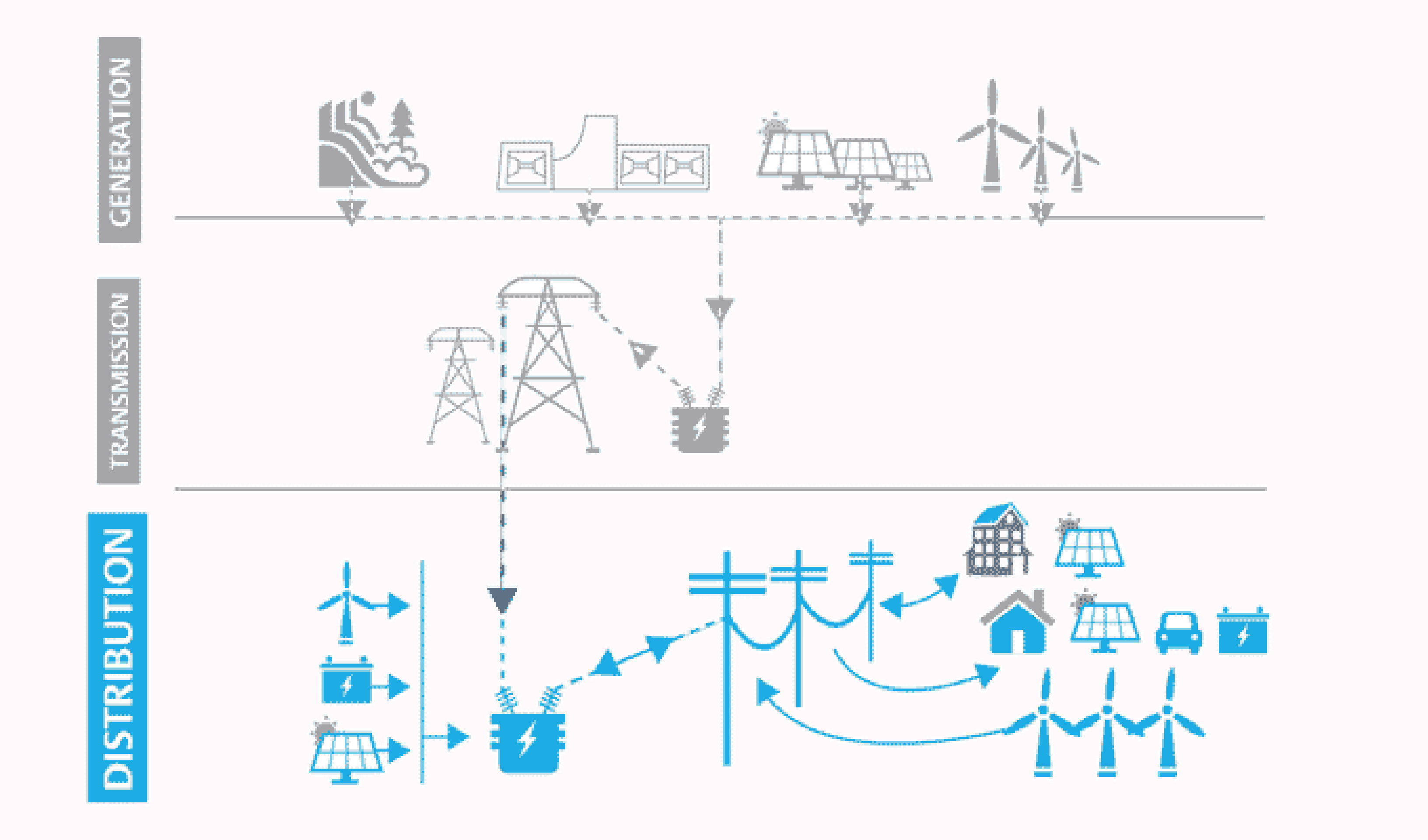
2. Transformation of voltage levels is simple, providing great flexibility of different voltage levels at generation, transmission and distribution.

3. AC motors, widely used, are simpler and more economical than DC motors.

Introduction



Introduction



In modern power systems, the grids are interconnected and vary widely in size and structure. However, they comprise three phase systems, at both **generation** and **transmission**.

1. **Synchronous generators** (alternators) are used for generation.
2. The **prime movers** (primarily turbines) act to convert **mechanical energy** into **electric energy**.
3. **Thermal plants** use coal as the primary fuel and hydel plants use water to run the turbine.
4. The generated power is transmitted over a wide geographical area, at **voltage levels higher** than the generated voltage.
5. **At the consumer end, the voltage is again stepped down** and distributed to various consumers. Consumers of different types need voltages of different levels.

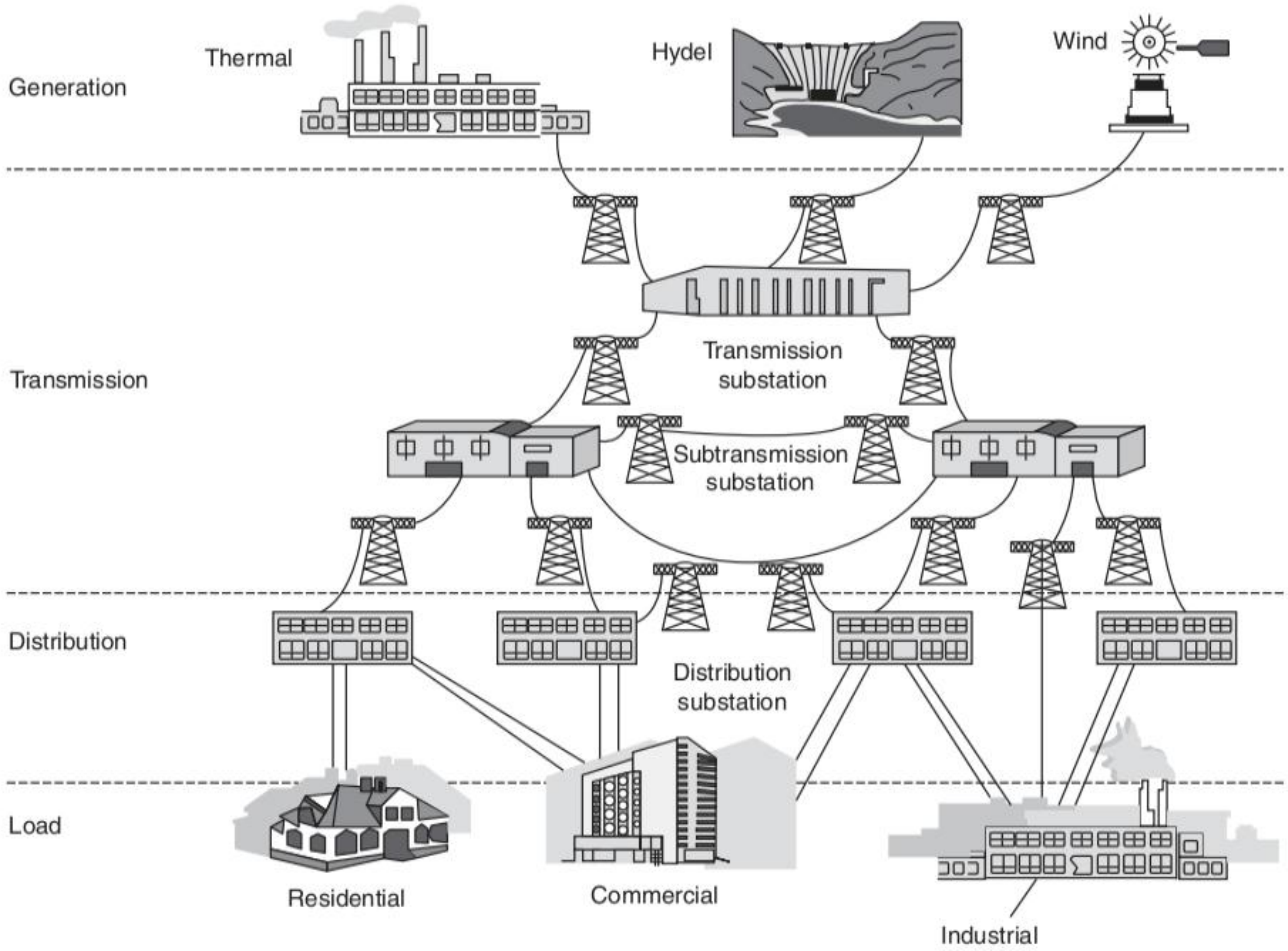


Figure 1.1 Basic structure of a power system.

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Key Components:

1. Power Generation:

1. India has a diverse energy generation mix:
   1. **Coal**: Dominates the generation mix, accounting for about 52% of total installed capacity (September 2023).
   2. **Renewables**: Solar, wind, hydro, and biomass contribute significantly, with renewables making up about 43% of installed capacity.
   3. **Gas**: A smaller percentage is generated from natural gas, around 7%.
   4. **Nuclear**: About 1.7% of the total capacity.
2. **Total Installed Capacity** (as of July 2023): **~417 GW** (417,668 MW).

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2. Transmission:

India has one of the world's largest transmission networks:

- **National Grid**: Operates on 765 kV, 400 kV, and 220 kV levels.
- **Inter-State and Intra-State Grids**: Managed by POSOCO at the national level and respective State Load Dispatch Centers (SLDCs) at the state level.
- **Grid Frequency**: Controlled within a narrow band of 49.90 Hz to 50.05 Hz, essential for maintaining stability and synchronism across regions.

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3. Control Centers:

- **National Load Dispatch Centre (NLDC)**: Oversees grid operation at the national level, under POSOCO.
- **Regional Load Dispatch Centers (RLDCs)**: There are 5 RLDCs (North, South, East, West, and Northeast) managing their respective regional grids.
- **State Load Dispatch Centers (SLDCs)**: Each state has an SLDC responsible for intra-state grid management.

4. Renewable Energy Integration:

- India's renewable energy target is **500 GW by 2030**. To manage intermittency, forecasting and scheduling have become essential.
- Special Energy Management Systems (SEMS) have been deployed to monitor real-time renewable energy generation.
- Green Energy Corridors are being built to facilitate transmission of renewable power.

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5. Demand-Supply Management:

SCADA (Supervisory Control and Data Acquisition): Used to monitor grid parameters and control generation in real-time.

Automatic Generation Control (AGC): Implemented for frequency regulation and balancing.

Real-Time Market (RTM): A platform for electricity trading in real-time to address short-term supply-demand gaps.

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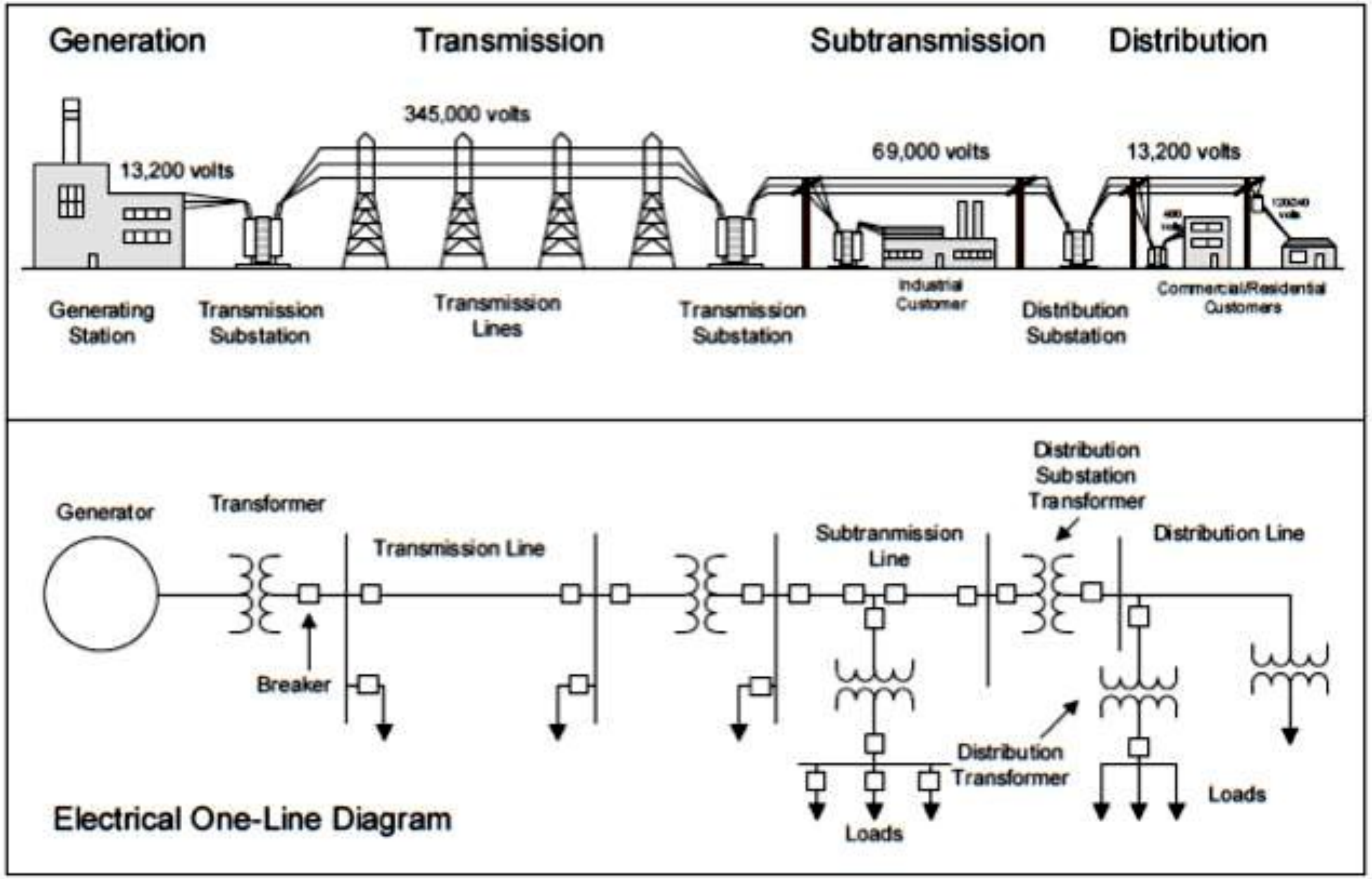
Statistics (as of September 2023)

Total Installed Capacity: 417,668 MW.

- **Coal**: ~207 GW (52%).
- **Renewable Energy**: ~180 GW (43%).
  - Solar: ~71 GW.
  - Wind: ~44 GW.
  - Hydro: ~47 GW.
  - Biomass: ~10 GW.
- **Gas**: ~25 GW (7%).
- **Nuclear**: ~6.8 GW (1.7%).

Peak Demand Met: Approximately 240 GW (July 2023), showing the rapid growth in electricity consumption.


Generation
Transmission
Subtransmission
Distribution
345,000 volts
13,200 volts
69,000 volts
13,200 volts
Generating Station
Transmission Substation
Transmission Lines
Transmission Substation
Industrial Customer
Distribution Substation
Commercial/Residential Customers
Generator
Transformer
Transmission Line
Breaker
Subtranmission Line
Distribution Substation Transformer
Distribution Line
Distribution Transformer
Loads
Loads
Electrical One-Line Diagram

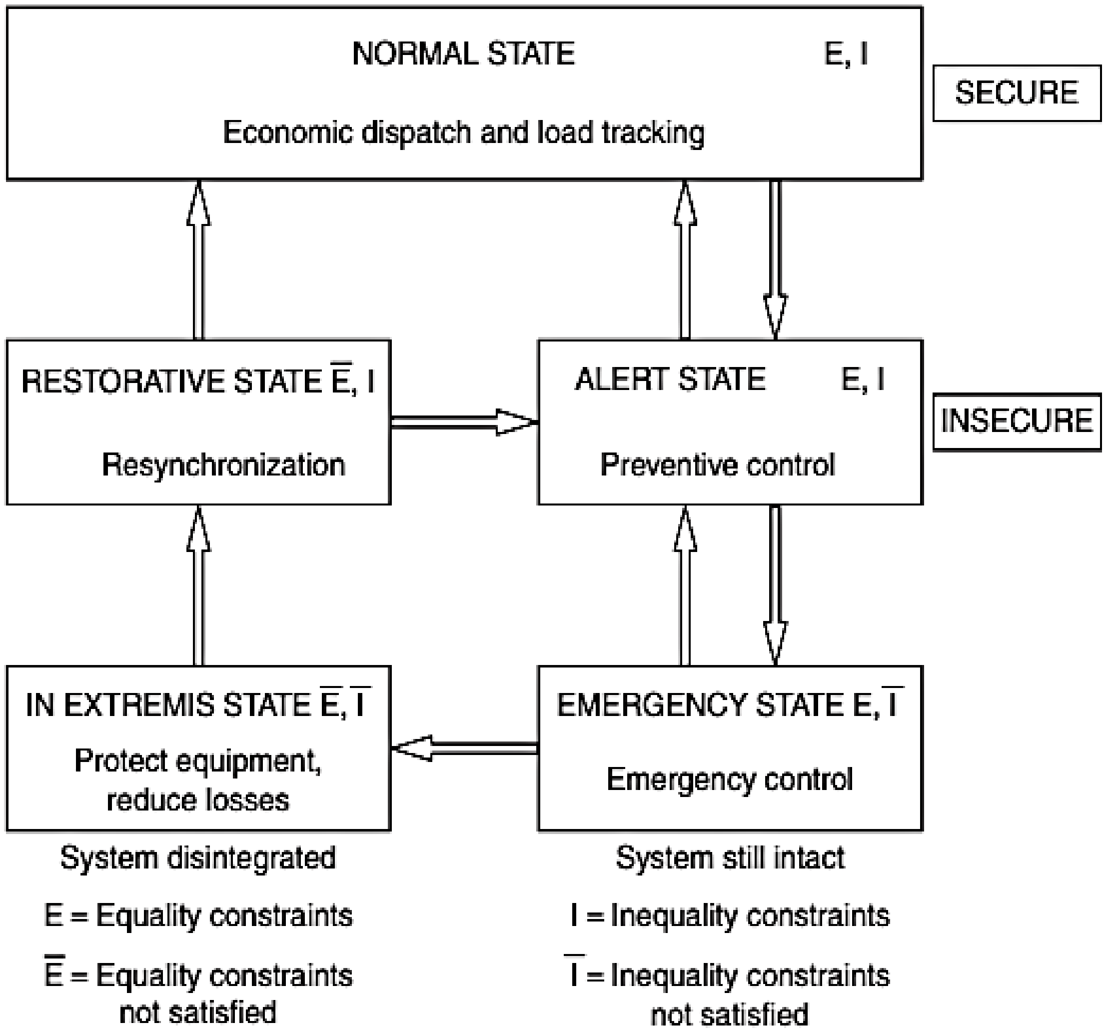
1.1 Operating States of a Power System

The system operation is governed **equality and inequality constraints**

Equality constraints means Power balance between **Generation** and **Load**

Inequality Constraints sets limits on operating parameters: Voltage, generation limits, current etc

Operating States of a Power System



Operating States of a Power System

- **Normal State:** In this state both equality and inequality constraints are **satisfied.**

- **Alert State:** In this state both equality and inequality constraints are **satisfied. However, reserve margins are reduced due to disturbances. Preventive control is incorporated**

- **Emergency State:**

Due to severe disturbance the system enters emergency state due to imbalance between generation and load, due to faults.
Methods like <u>indirect load shedding</u>, <u>generation shedding</u>, <u>shunt capacitor</u> etc is incorporated

Operating States of a Power System

- **In extremis State**: Both equality and inequality constraints are not **satisfied. Emergency measures must be taken before grid collapse.**

- **Restorative state**: **Transitional state to normal or alert state**

Operating States of a Power System

1. Normal State:

The power system is operating within prescribed limits, and all generators, transmission lines, and loads are functioning normally.

•**Equality Constraints**:

- **Power Flow Equations**: PGeneration=Pload+Ploss
- **Voltage and Current Balance**

•**Inequality Constraints:**

- **Generator Output Limits**: Active power (P) and reactive power (Q) output must remain within specified operational limits for each generator.
- **Transmission Line Limits**: Line currents and thermal capacities must not exceed their rated limits.
- **Voltage Limits**: Bus voltages must remain within specified thresholds (e.g., ±5% of nominal voltage).

Operating States of a Power System

Operating State	Equality Constraints	Inequality Constraints
Normal	- Power flow equations (generation = demand + losses)	- Generator output within limits - Transmission line loading within limits - Voltage within nominal range
Alert	- Power flow equations - Voltage/current balance	- Generators/lines near limits - Contingency constraints (N-1 security) - Potential overloads approaching
Emergency	- Power flow equations - Some imbalances may occur	- Generator/line overload - Voltage and frequency deviations - Load shedding may occur
In Extremis	- Power flow equations may fail to hold	- Severe overloads - Voltage and frequency collapse - Large-scale load shedding/blackout risk
Restorative	- Gradual restoration of power flow and balance	- Generator ramping - Gradual load restoration - Recovery of voltage and frequency within limits

PAUSE

1) State with the Most Sophisticated Power System Monitoring Mechanism in India:

Maharashtra is often cited as one of the leading states in power system monitoring and management. It has advanced **Supervisory Control and Data Acquisition (SCADA)** systems and has made significant investments in **Automatic Generation Control (AGC)** and **Energy Management Systems (EMS)**.

2) State with Highest Generation and State with Highest Power Usage:

Highest Generation: **Maharashtra** is the state with the highest power generation capacity, thanks to its extensive thermal and renewable energy plants, contributing around 44,000 MW of installed capacity.

Highest Power Usage: **Maharashtra** also has the highest power consumption in India due to its industrialized economy, large urban centers like Mumbai, Pune, and Nagpur, as well as a high population.

3) State with Highest Power Wastage:

Uttar Pradesh is among the states with the highest power wastage, primarily due to high **Transmission and Distribution (T&D) losses**. These losses are caused by issues like inefficient infrastructure, electricity theft, and technical losses in the grid.

Uttar Pradesh has historically seen T&D losses around 25-30%, significantly above the national average. Efforts are being made to reduce these losses, but the state still struggles with power wastage.

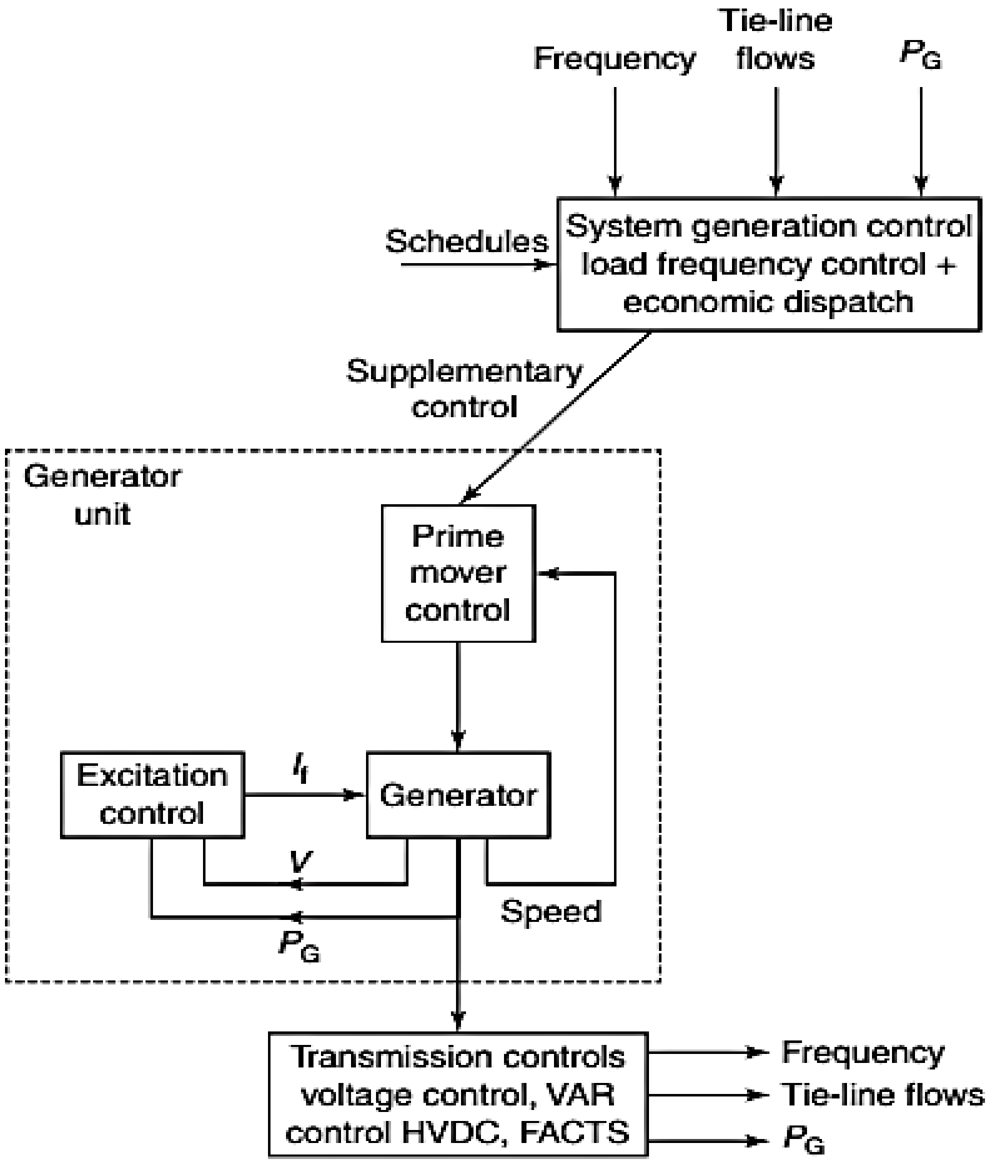
1.2 Objectives of Power System Control:

- The system must be able to meet the changing demand between **active and reactive power**.

---→ Spinning reserve helps in maintaining it

- The Power quality should meet certain standards such as **frequency, amplitude and wave shape.**
- Energy should be supplied at **minimum cost**

- To achieve generators-→ are provided with excitation control to maintain voltage
- Prime movers---→ to maintain frequency
- Power system stabilizers to damp oscillations in generators subjected to disturbance
- System Automatic Generation Control(AGC) maintains the active power balance.
- Transmission & Voltage Control devices helps to maintain voltage
- Distribution controls such as capacitors, wave shaping circuits helps to provide quality supply.


Frequency
Tie-line flows
P_G
Schedules
System generation control load frequency control + economic dispatch
Supplementary control
Generator unit
Prime mover control
Excitation control
I_f
Generator
V
P_G
Speed
Transmission controls voltage control, VAR control HVDC, FACTS
Frequency
Tie-line flows
P_G

1. 3 Operation & Control of a system

Stability : Continued interact operation of a system following a disturbance.

Security: Power system stability to survive contingencies without interruption to the consumer.

Reliability: Probability of s satisfactory operation over a long period.

1.4 Key Concepts for Reliable Operation

Power System Control Mechanism using Automatic Generation Control (AGC) in brief

Step	Description
Real-Time Data Collection	Grid parameters (frequency, generation, demand) are monitored via SCADA systems.
Signal Transmission	Control centers (e.g., NLDC) send signals to power plants when frequency deviates from 50 Hz.
Automatic Adjustments	Power plants automatically adjust generation to restore grid frequency.
Continuous Feedback Loop	System continuously monitors adjustments and ensures real-time corrections to maintain stability

1.4 Key Concepts for Reliable Operation

- **Balance the generation and Load**: AGC is used to match the generation with demand.
- **Balance reactive power generation and demand** :FACTS devices are used for reactive power control
- **Ensure thermal limits are not exceeded:** Heating limits of overhead lines must not be exceeded

- **Maintain system stability:** Regain state of equilibrium after subjected to disturbance.
- **Meet N-1 reliability criteria:** System should remain operational and secure even after the loss of large generator.
- **Plan, Design and maintain to Operate reliably**: safe limits planning(short term and long term)
- **Prepare for emergencies:** weather fluctuation, operator error, software failure, equipment failure. Operators must be trained

1.4 Preventive and Emergency Controls

Preventive control : Means maintain system in normal state or bring it back to normal state.

1. Rescheduling of Active power generation, to maintain the changing loads.
2. Start up of generation and maintaining adequate spinning reserve.
3. Change of reference points of FACTS controllers, phase shifting transformers
4. Change in the **reference voltage points** of generation and voltage control devices.
5. Change in **bus bar configuration** like bus bar splitting

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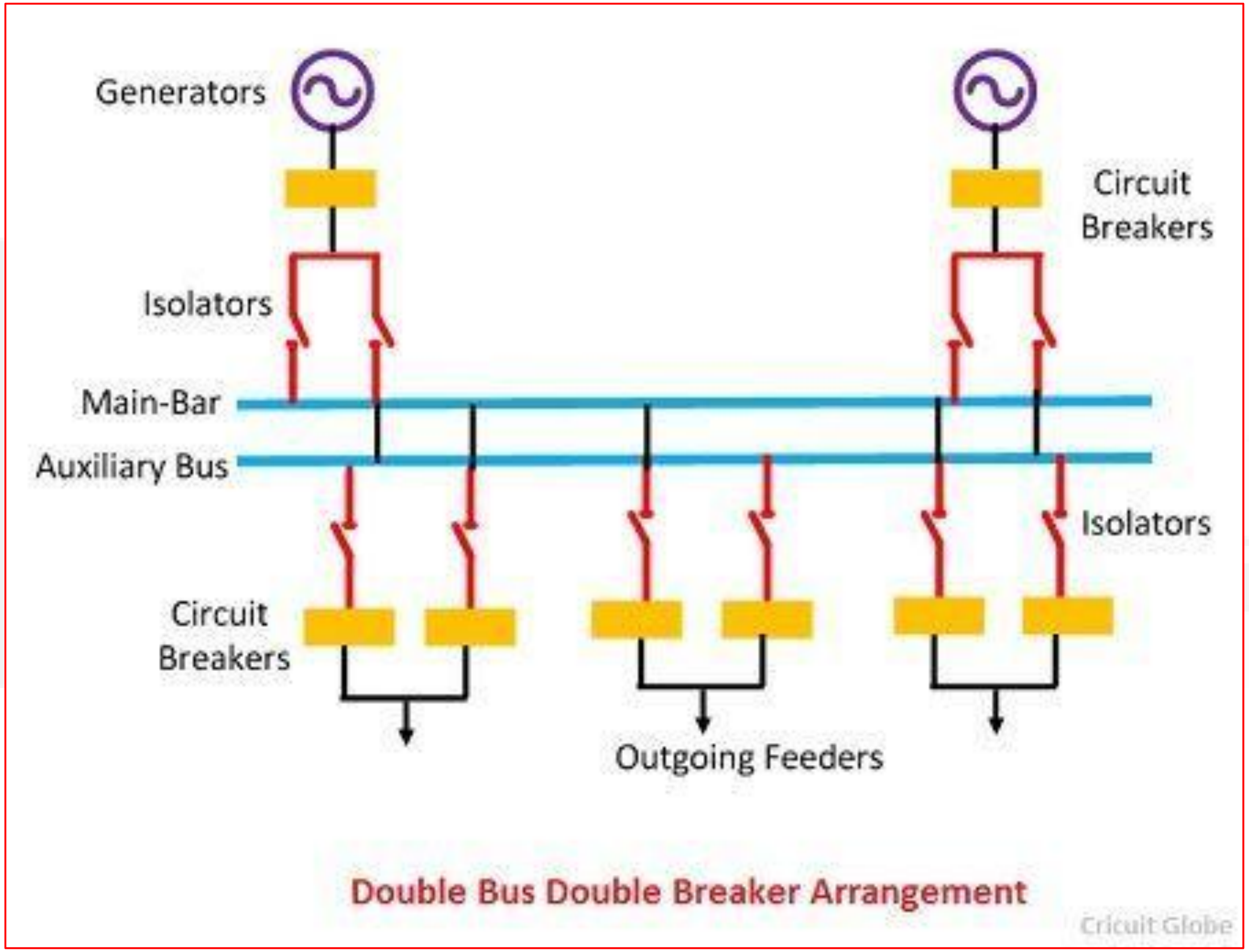

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FACTS CONTROLLERS

- The FACTS controller is defined as a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters.

WHY FACTS CONTROLLERS

- Earlier days Mechanical Circuit Breakers like Relay, Contactors etc are used to control the power flow of the transmission systems.

- Mechanical Circuit Breakers was not very reliable and they can not compensate the power loss due to Reactive Power of the transmission systems.

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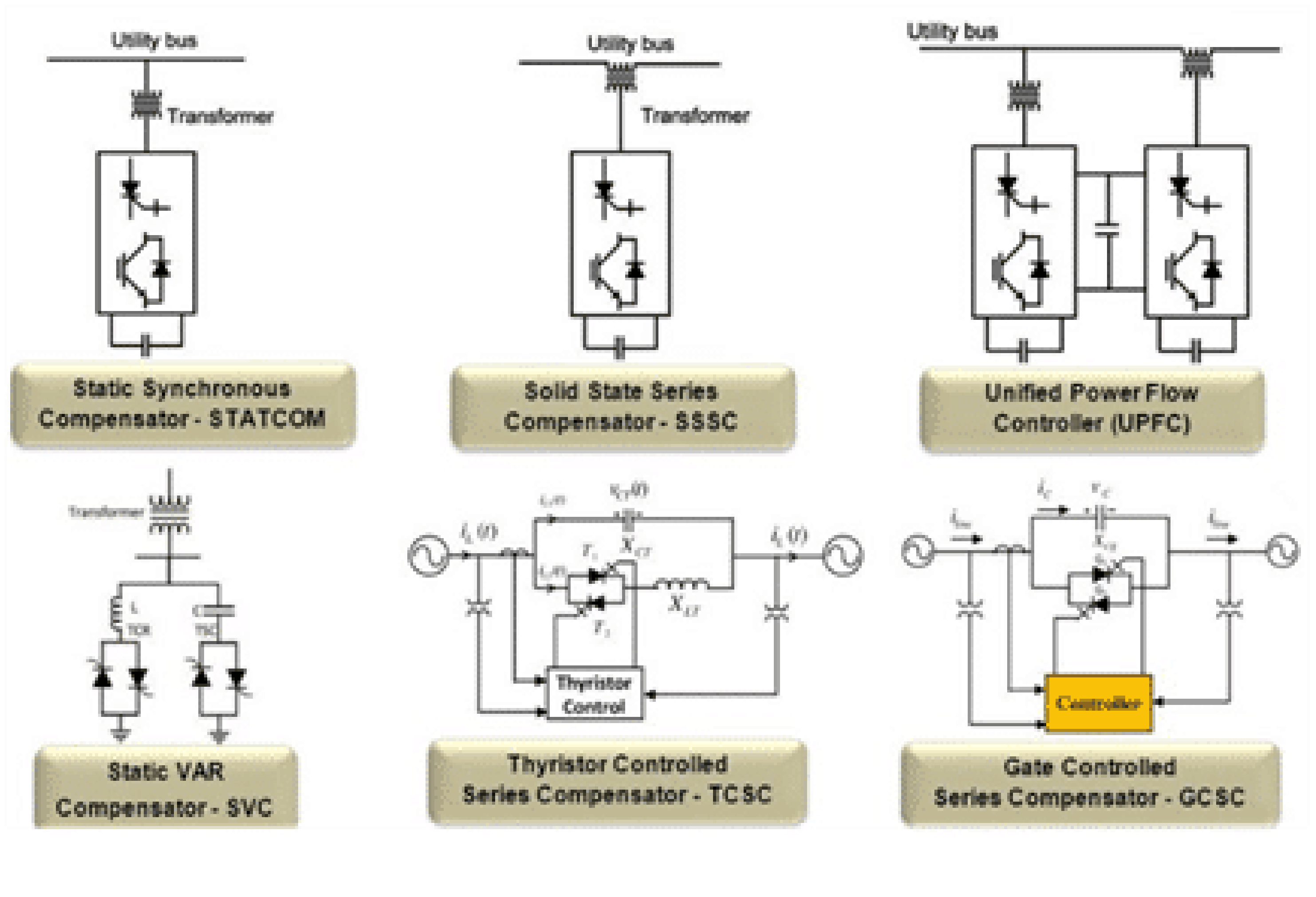

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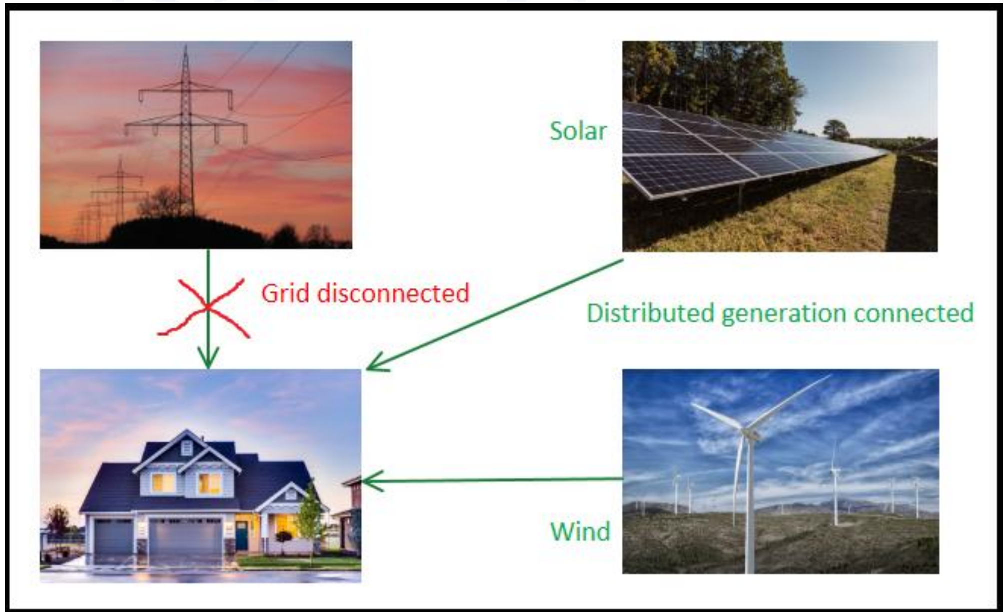
Emergency Controls:

1. Tripping of generators
2. Load shedding
3. Controlled disconnection of interconnected systems
4. Fast HVDC power transfer control
5. Application of braking resistors
6. Controlled islanding to create local generation load balance.



1. 5 Energy Management Centers.

The functions of an **energy sub center** can be divided into three sub systems:

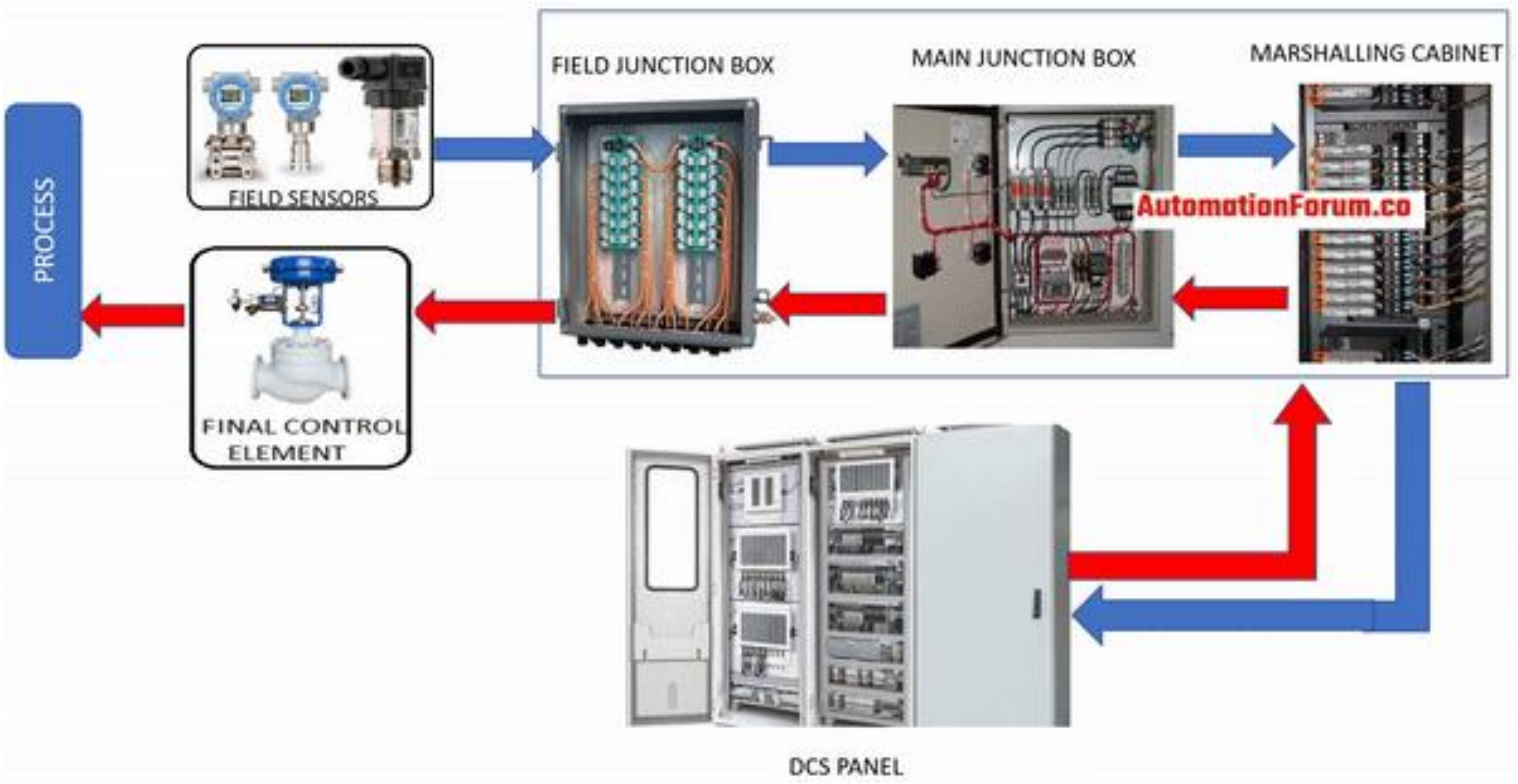
1. **Dispatch Subsystem**: Unit Commitment, Economic Load dispatch, AGC and Load forecasting
2. **Data Sub system**: Data acquisition and processing
3. **Security subsystem**: Secure operation of the power system

The hierarchical control can be broadly classified into three levels:

1. **Level 1**: Load forecasting, unit commitment, trading (**longer duration**).
2. **Level 2**: Economic dispatch, optimal power flow, interchange evaluation (**duration around 5–10 min**).
3. **Level 3**: Automatic generation control, voltage control, state estimation (**time in seconds**).

Level 1 functions require statistical data and hence probabilistic methods are used. The results of level 1 are used in level 2 and level 3 functions. These are mainly deterministic in nature.

Major Components of Energy Centers



Major Components of Energy Centers

1.SCADA: The SCADA system consists of two subsystems – the **supervisory control** and the **data acquisition**.

The supervisory subsystem is responsible for:

(a) **display at the central location**, the status of circuit breakers and other devices such as tap changers, capacitor switching, generator voltage regulators

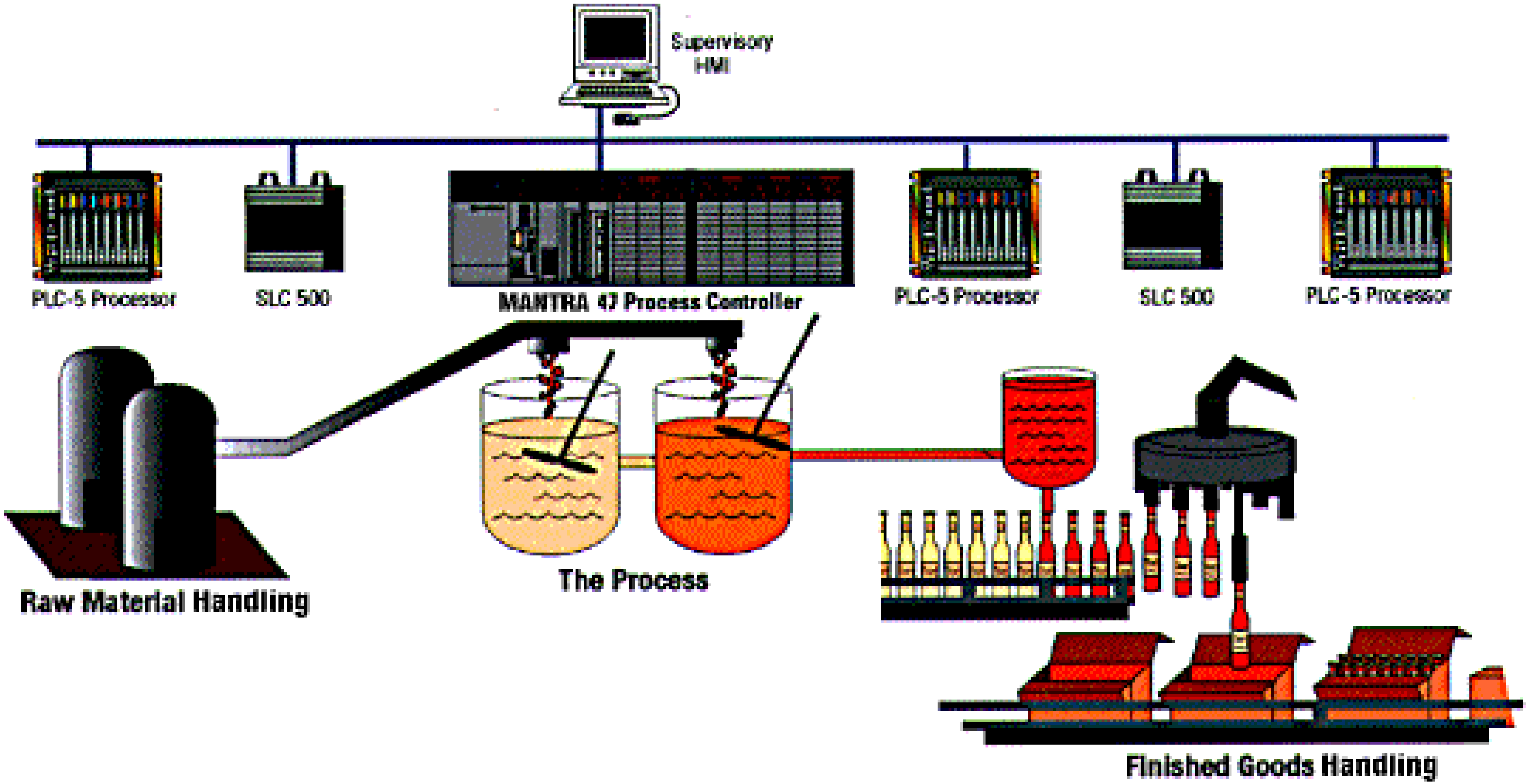
(b) facilitating remote tripping of breakers, tap changing of transformers, etc.

2. Computers: The main functions of the computing facilities at the control center are as follows:

- Real-time monitoring and control
- User interface
- Operating studies
- Maintenance and testing
- Simulation studies

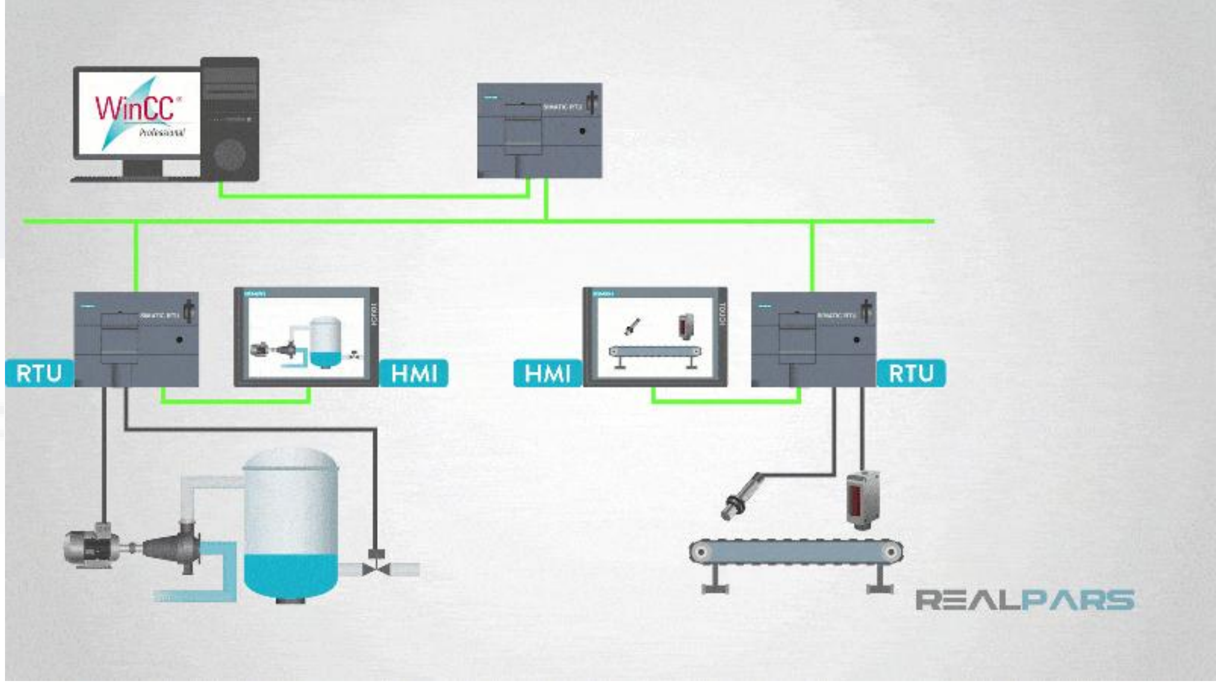
3. User interface (with extensive GUI and display facilities): The user interface consists of consoles, data loggers, display units and screen projections to alert operators.

4.Applications software: This section is to implement the various functions discussed, namely, Unit Commitment, economic dispatch, state estimation, optimal power flow, contingency analysis, etc.


Supervisory HMI
PLC-5 Processor
SLC 500
MANTRA 47 Process Controller
PLC-5 Processor
SLC 500
PLC-5 Processor
Raw Material Handling
The Process
Finished Goods Handling

1.6 Supervisory Control and Data acquisition (SCADA):

- Introduction, components,
- Application in Power System,
- Basic functions and advantages.
- Building blocks of SCADA system,
- Components of RTU,
- Communication subsystem
- IED functional block diagram.



1.6.1 Introduction to SCADA and its Components

- Supervisory Control and Data Acquisition is a combination of **Supervisory Control** and **Data Acquisition with associated telemetry.**
- **It is used control equipment which is geographically dispersed.**
- **It consists of both Hardware and Software**
- **SCADA is only for supervisory control and does not include full control system.**

SCADA

- **Objective: To control Specific device to make it perform with a directed action**

Supervisory Systems in Power Systems:

a) SCADA:

1. Traditional generations of data acquisition and control systems
2. Limited amount of **record keeping and data reporting.**

SCADA

b) SCADA/AGC

1. Similar to SCADA except AGC is included to calculate **area control error, monitoring system frequency, tie-line interchange, economic dispatch**.

c) EMS(Energy Management Systems)

1. Includes all features of SCADA and other extensions such as **load flow, contingency analysis, state estimation.**

SCADA

d) Telemetry

Refers to transmitting and receiving information or data over a medium.

1. **Typical data in power systems: Measurement of voltage, power flow, circuit breaker status.**
2. **Information is transmitted through cable, telephone, internet, radio.**

SCADA

e) Data Acquisition

Refers to the method used to access & Control the information or data from the equipment that is controlled or monitored.

Data Acquisition

1. Data(Analog or digital) is then forwarded through telemetry system.
2. Data is obtained from sensors, meters, actuators, control equipments like relays, valves etc.
3. DMS: Distributed management Systems: Monitor and control distribution feeder loads. It includes topology analysis & load flow programs.

Data Acquisition

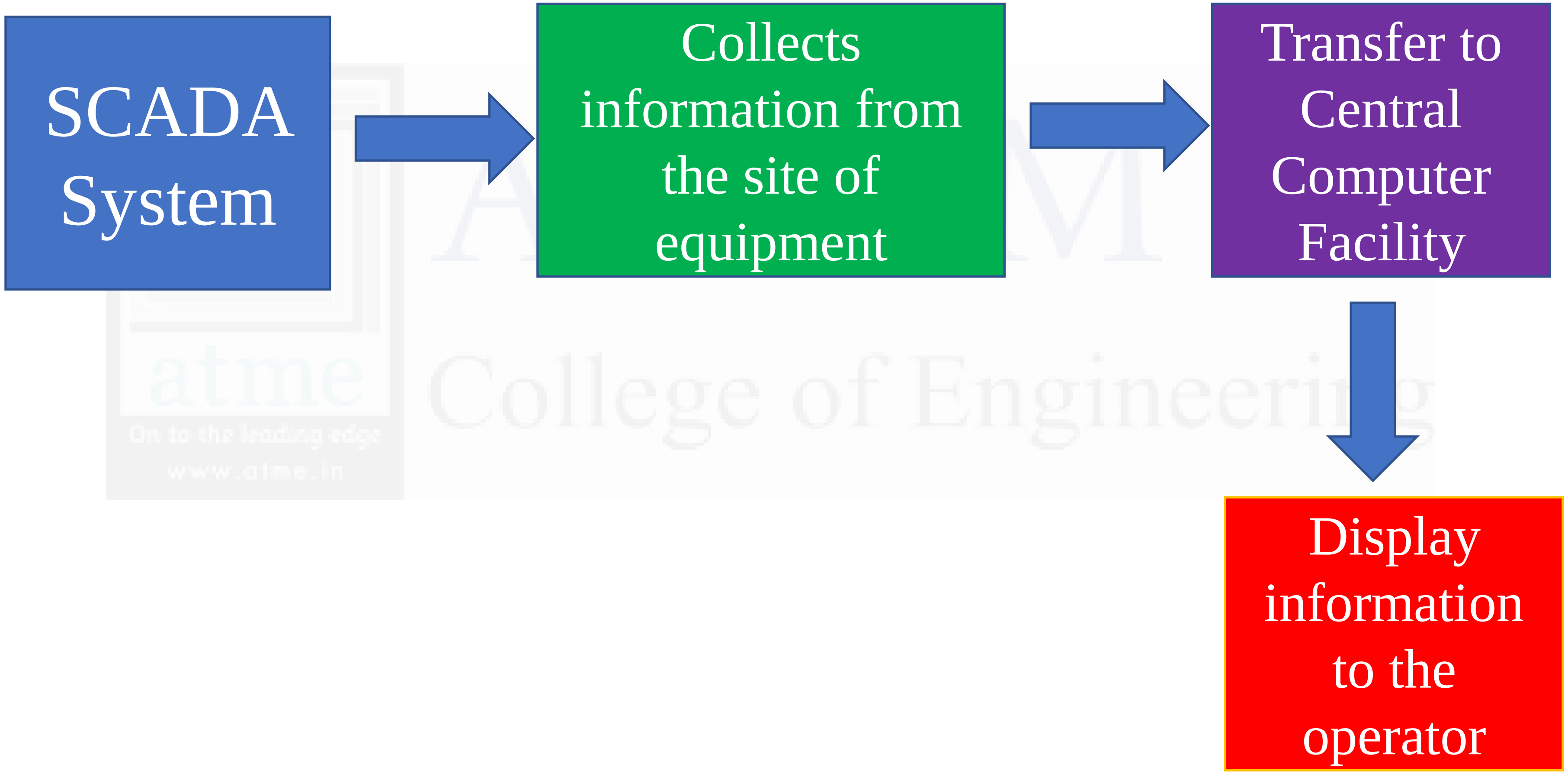
4. LMS(Load Management System) :

Manages the peak load & is used in <u>Demand side management.</u>

It can be standalone or integrated with EMS or DMS

5. AMR (Automatic Meter Reading) is incorporated in LMS.

1.6.2 Components of SCADA Systems



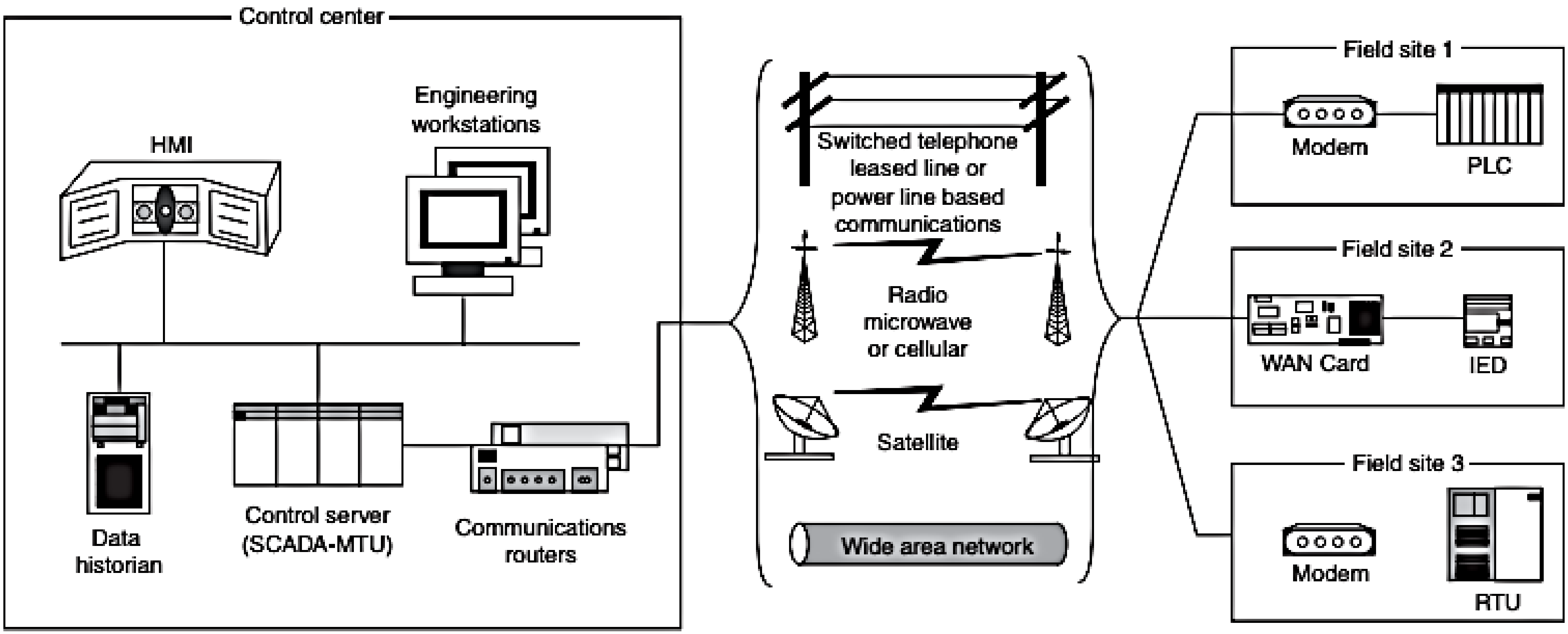


Figure 12.1 General SCADA configuration.

Major Components of SCADA System

- **Field Instrumentation:**

1. Refers to all **sensors and actuators** interfaced to equipment.
2. Generates analog and digital signals
3. Analog outputs have standard industry values:0-5V, 0-10V, 0-20mA.
4. Digital Outputs- Status of equipment: ON-Off, Full-Empty, Open-Closed.

Major Components of SCADA System

- **Remote Station**

1. Field Instrumentation connected to Plant/Substation/ equipment which is being monitored and controlled is interfaced to the **Remote station to allow manipulation at the remote site.**
2. **Remote Station May be:**

- **RTU:** Computer with good interfacing for communication and programming.
- **PLC:** Used in industries & has good programmability.

Major Components of SCADA System

- **Communication Network**

1. **Refers to communication equipment needed to transfer data to and from different sites.**
2. **Communication media:** RS232/RS-442/RS485, dial up telephone lines, microwave, satellite.
3. **Cables:** not practical for systems spread over wide geographical areas.
4. Ethernet: For server client, server-server communication

Major Components of SCADA System

- Central Monitoring Station

1. CMS is the master unit for SCADA System
2. Change of information collection from remote stations.
3. CMS Components:

- MMI or HMI program
- Mimic diagram of the whole system
- Display of RTUs with present I/O reading
- Window for alarms

Major Components of SCADA System

- **Software for SCADA**

1. **Software is based on Real Time Database.**
2. **SCAD Software: Proprietary: Developed by companies / Open source**
3. **Features: Graphic Displays, alarms, scalability, RTU/PLC interface, redundancy, networking etc.**

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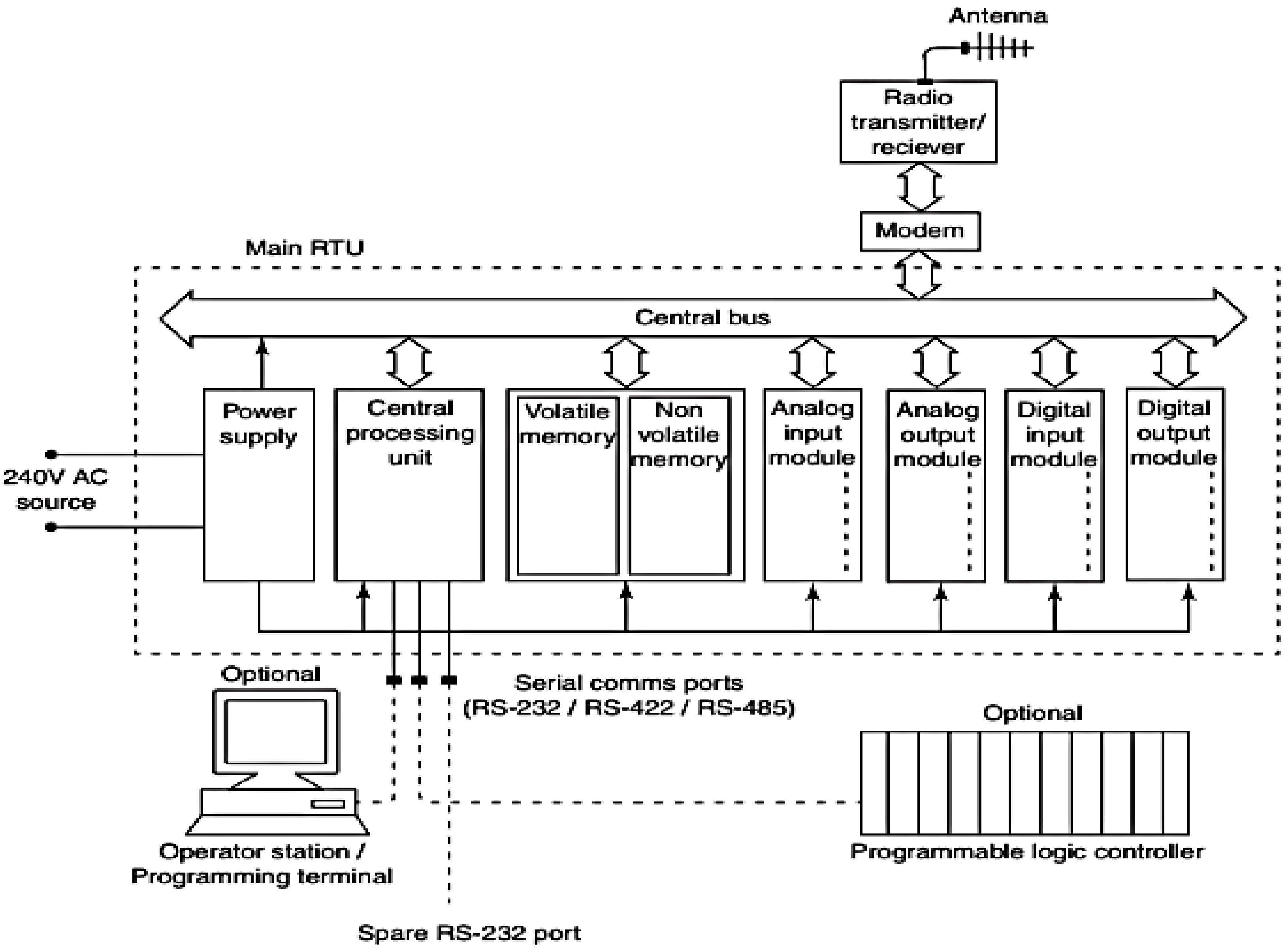


Figure 12.2 RTU unit.

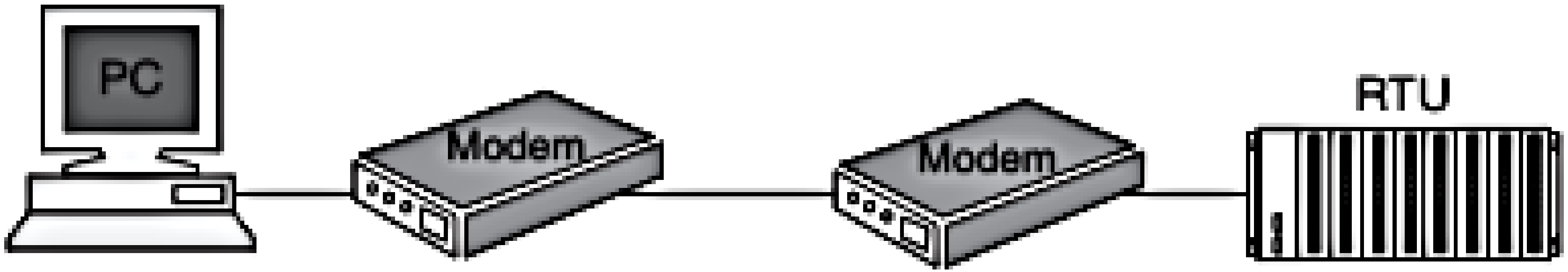


Figure 12.3 Use of telephone lines for communication.

Applications of SCADA in Power System

Application in Power Generating Station

- Continuous monitoring of **Speed and Frequency**
- **Geographical monitoring** of coal delivery and water treatment processes
- Supervising the **status of circuit breakers, protective relays** and other safety related operations
- Generation operations planning
- **Active and reactive power control**
- Turbine protection
- Load scheduling
- Historical data processing of all generation related parameters

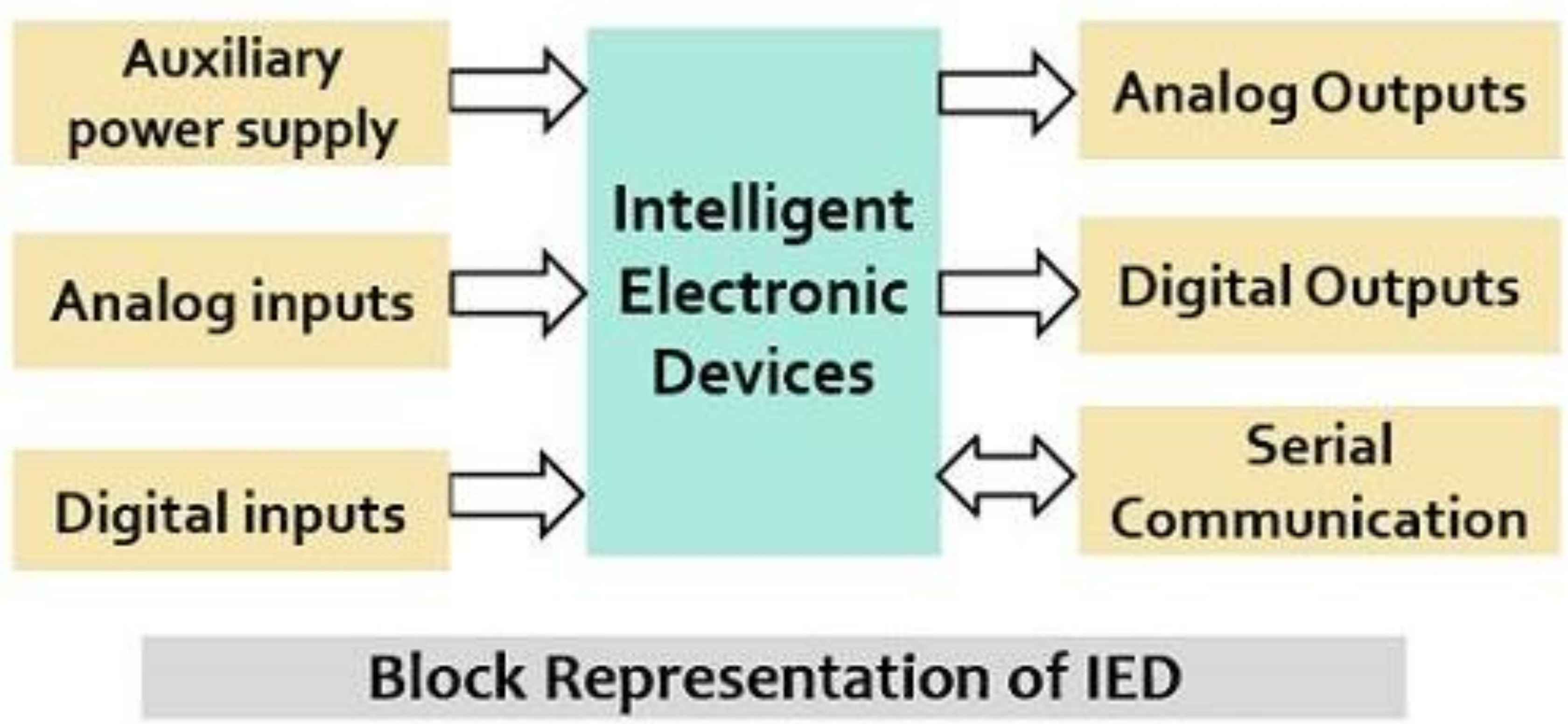
Application in Power Distribution

- Improving power system efficiency by maintaining an acceptable range of power factor
- Limiting peak power demand
- Continuous monitoring and controlling of various electrical parameters in both normal and abnormal conditions
- Trending and alarming to enable operators by addressing the problem spot
- Historian data and viewing that from remote locations
- Quick response to customer service interruptions

Intelligent Electronic Devices (IED)

- It is defined as devices that have single or multiple microprocessors integrated within it.
- Its main purpose involves the transmission or reception of data or control signals to or from an external device.
- The external device in consideration with the whole system can be transducers, relays, control units, etc.
- IEDs are regarded as a key part of industrial control systems used for the purpose of advanced power automation.
- Thus, is useful in **S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition systems (**SCADA** system), **D**istributed **C**ontrol **S**ystems (**DCS**) as a crucial component.

Block diagram Intelligent Electronic Devices (IED)



- **Auxiliary Power Supply**: An auxiliary power supply or source is basically an electric power supplied by a backup alternate source other than the primary main source. IEDs always need an auxiliary power supply, unlike older protection relays where an auxiliary power supply is of not much significance. So, the acceptable power supply used by IEDs is in the range between **15** to **150 volts** in the case of **DC**. While **110** to **140 Volts** when **AC**.
- **Analog Inputs**: In relays, inputs are provided by the current transformer and potential transformers. However, IEDs may have sensor inputs.
- **Digital Inputs**: Digital inputs provided to the IEDs may be some sort of commands or any status information. Some of these need potential free contacts while some understand with the consideration of logic 0 or logic 1 as negative voltage and positive voltage respectively.
- **Analog Outputs**: Generally, transducers are used to get the output from the IEDs which is programmable type. The output can be of active or passive nature but a passive type output requires an external power supply.
- **Digital Outputs**: In the case of digital outputs, the potential contacts can be normally open, normally closed, or solid-state contacts. Similar to digital inputs, digital outputs are also commands or status information, and the switching capability must be properly checked as the significant differences can be noticed.

Standard SCADA Configurations

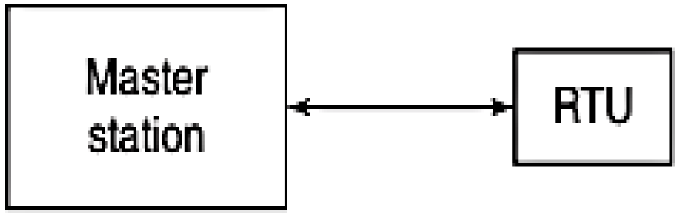
We have two distinct layers in a SCADA system: **the client layer** that caters to the MMI and the **data server layer** that handles most of the data control activities.

The data servers communicate with the RTUs and are connected to them either directly or via networks or field buses that are proprietary (e.g., Siemens, H1) or non-proprietary (Profibus). Data servers are connected to each other and to client stations via LAN.

The master station and the RTUs can be connected in a number of different ways. They are shown as follows.

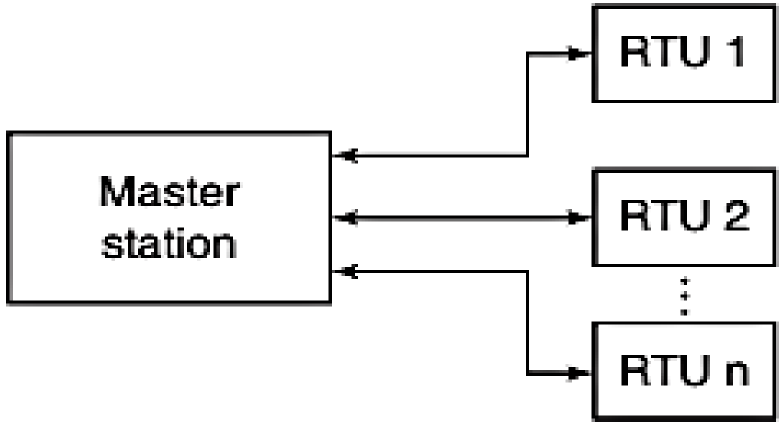
Single Master Station Configurations

1. Single master station and single RTU



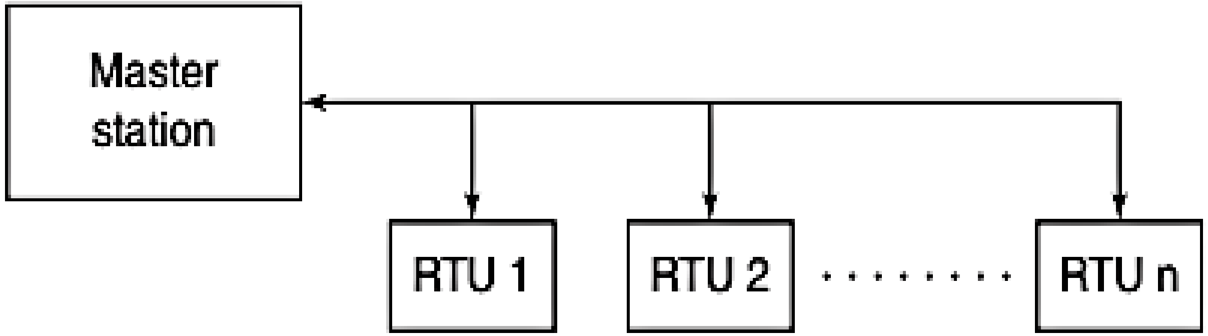
(a)

2.Single master station and multiple RTUs



(b)

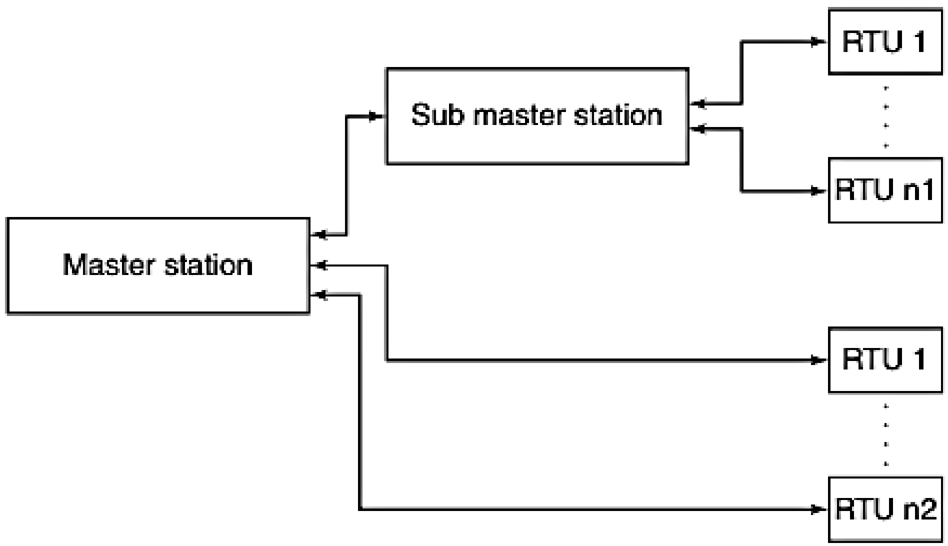
3. Single master station with multiple RTUs in multidrop circuit



(c)

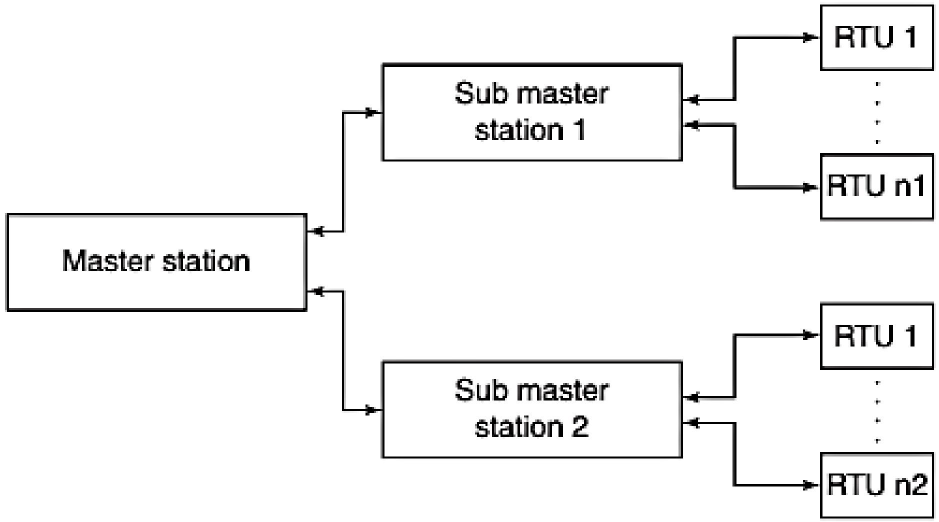
Multiple Master Station Configurations

1. Single dual ported RTU, radial circuit



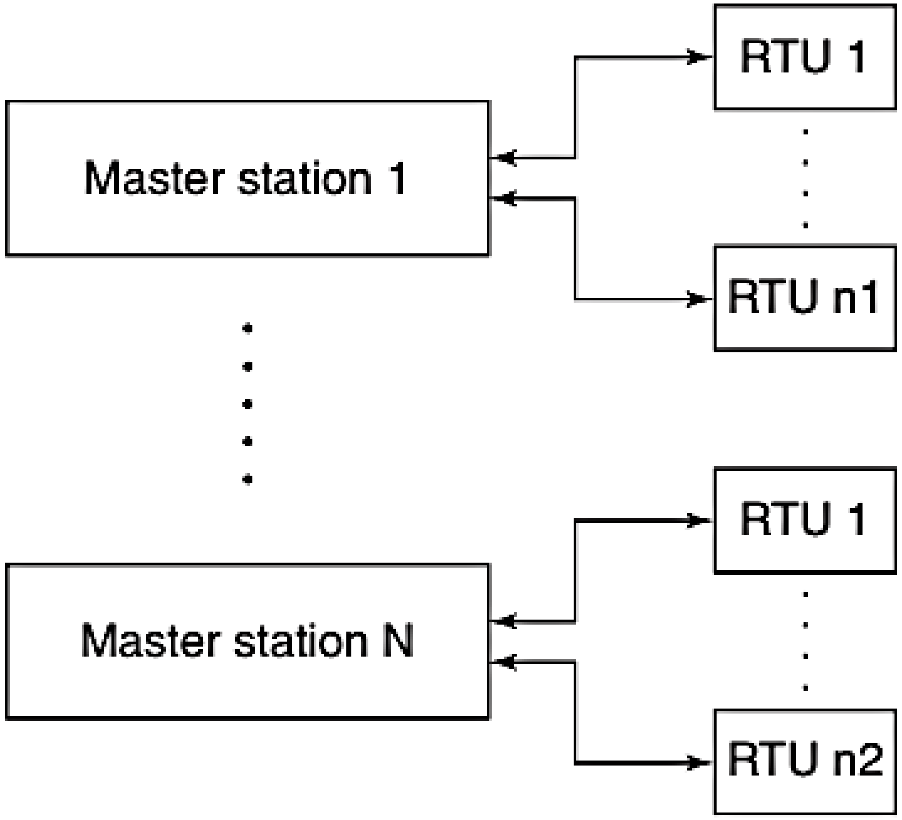
(a)

2. Multiple RTUs, multidrop circuit



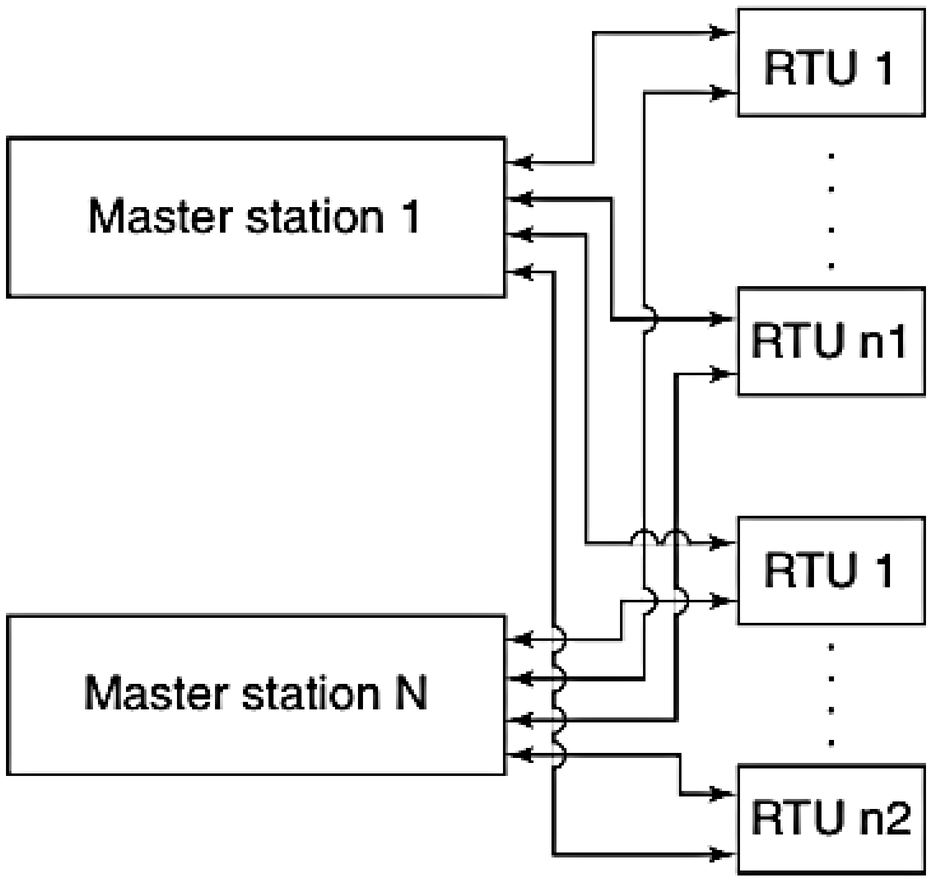
(b)

3.Multiple master stations, multiple single ported RTUs



(c)

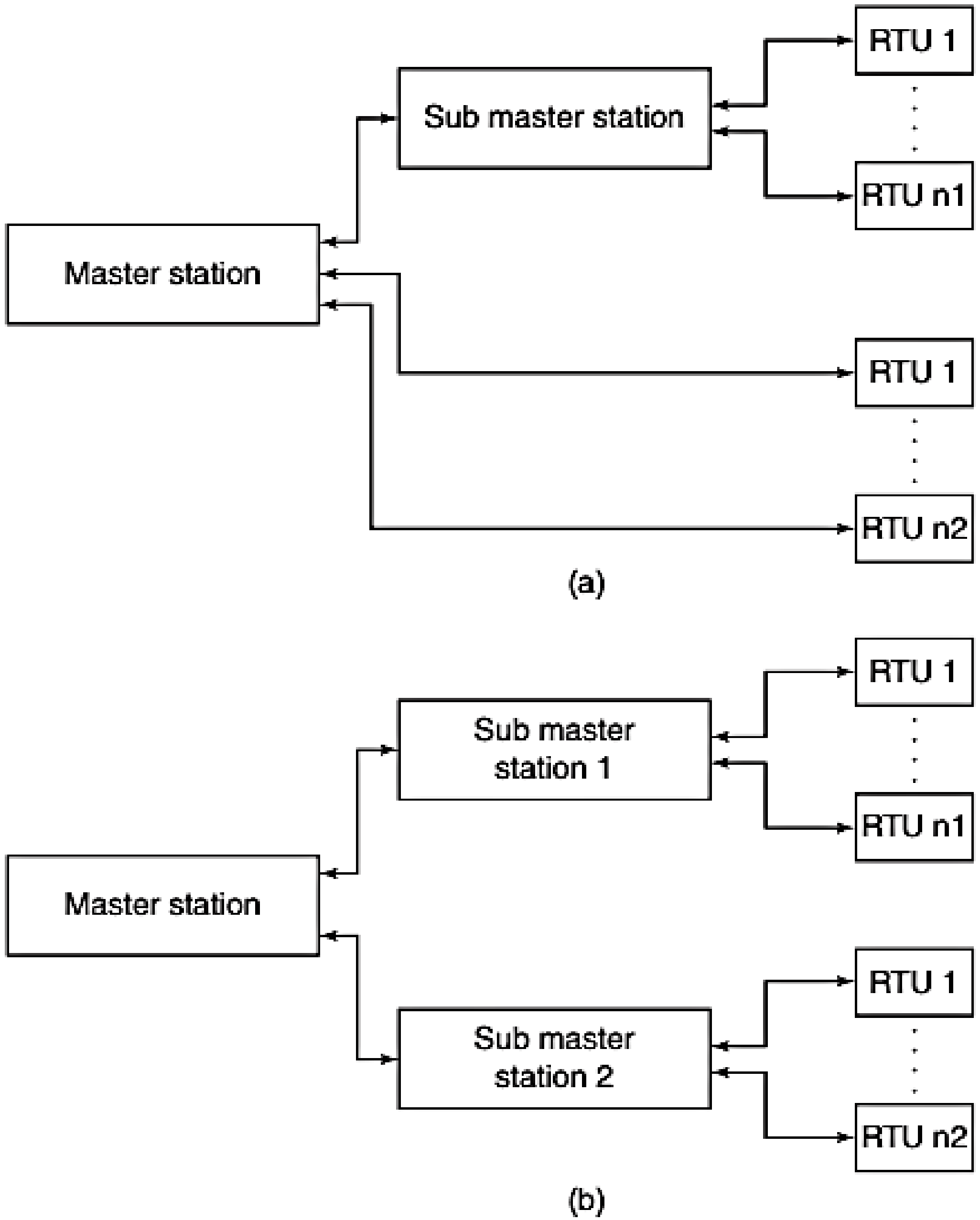
4.Multiple master stations, multiple dual ported RTUs.



(d)

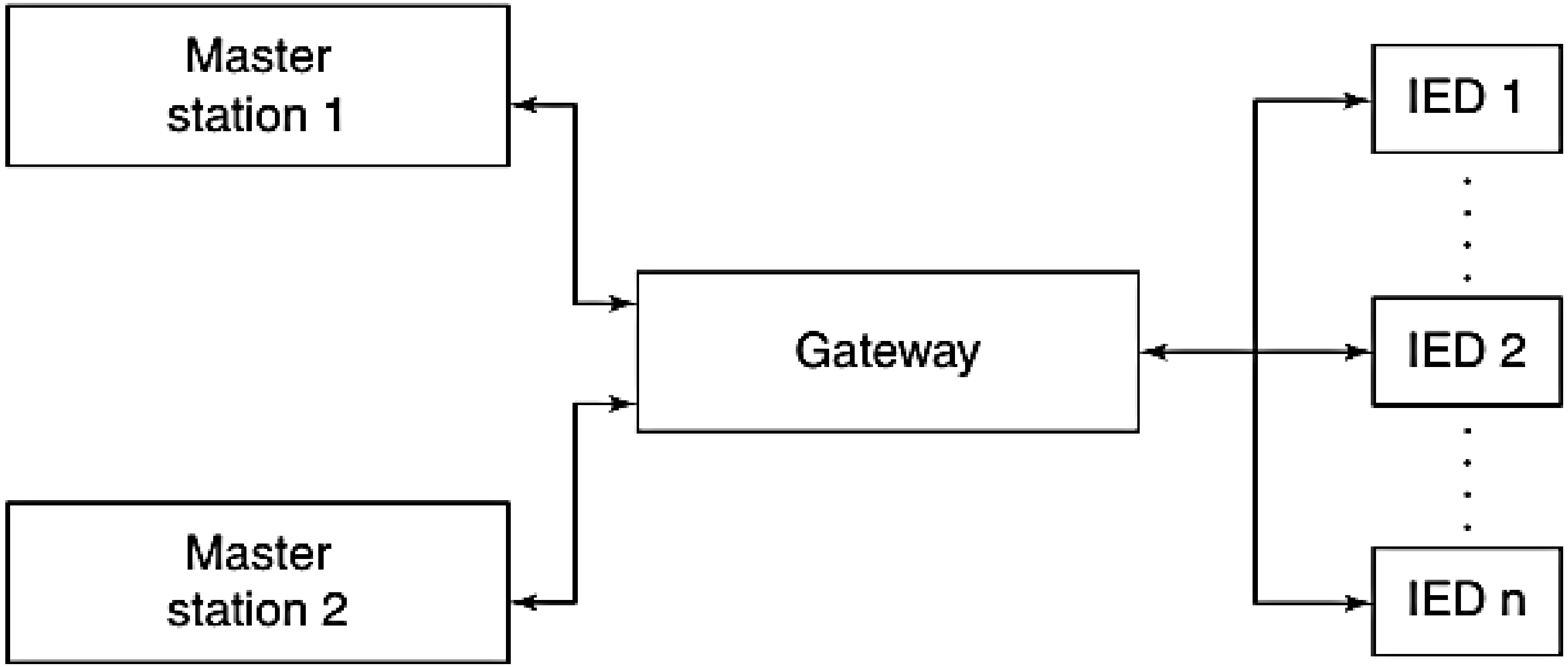
Combination Systems

These are a combination of master stations and sub-master stations. These are shown in Figure



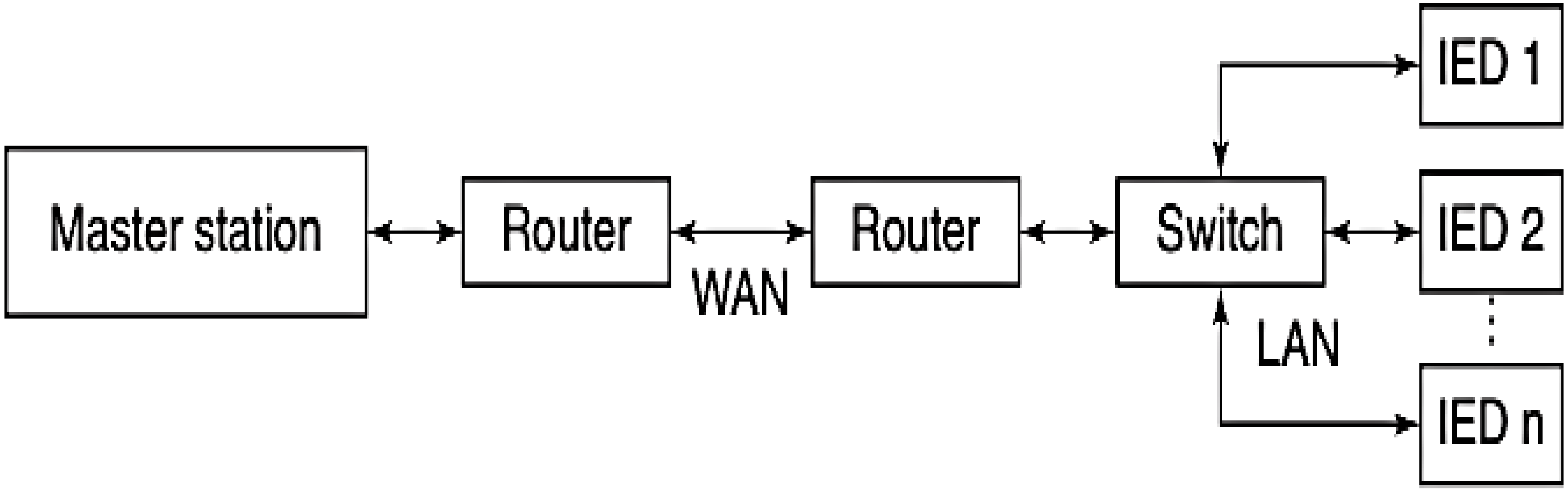
Systems with Gateway Connections :

With the prolific use of Ethernet, gateway connections have become popular. Such a connection is shown in Fig.



Networked Systems :

Drastic technological advancements in networking have made such systems popular. They use WAN/LAN for networking, through routers as shown in Fig.



Advantages of SCADA:

- The data can be displayed in a variety of formats based on the needs of the user.
- Real data simulations can be obtained with the assistance of operators.
- It provides an interface to connect thousands of sensors across the wide region for various monitoring and controlling operations.
- The system is capable of storing large amounts of data.
- Real data simulations can be obtained with the assistance of operators.
- Many types of data can be gathered from RTUs connected with the master unit.
- Data can be monitored from anywhere, not just the local site, thanks to advanced protocols and application software.
- It is fast in obtaining a response.
- The SCADA system incorporates unit redundancy to provide a backup in the event of faults or failures. This strengthens the system.

Thank You