

Distribution System Automation and Smart Grid

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Smart Grid: Definition

- The modernization of the grid by installing intelligent electronic devices in terms of sensor electronic switches, smart meters, and also advanced communication, and data acquisition and interactive software with real-time control that optimize the operation of the whole electric system and make more efficient utilization of the grid assets.
- Basically, **Smart grid=Electrical Grid+Advanced Communication+IT**

Smart-Grid: Essential Properties

- A smart grid is a grid that accommodates a wide variety of generation options, for example, central, distributed, intermittent, and mobile. It provides customers with the ability to interact with the energy management system (EMS) to adjust their energy use and reduce their energy costs.
- A smart grid also has to be a self-healing system. It foresees the forthcoming failures and takes the necessary corrective actions to avoid or mitigate system problems.
- A smart grid uses the IT to continuously optimize the employment of its capital assets while minimizing operational and maintenance costs.
- However, the smart grid should not be seen as a replacement for the present electric power grid but a complement to it. Thus, the smart grid can coexist with the present electric power grid, adding to its capabilities, functionalities, and capacities by means of evolutionary path.

Smart Grid: Different Components

- *Intelligent electronic device (IED)*: Any device incorporating one or more processors with the capability to receive or send data and control from or to an external source (e.g., electronic meters, digital relays, and controllers).
- *Remote terminal unit (RTU)*: The entire complement of devices, functional modules, and assemblies that are electrically interconnected to affect the remote station supervisory functions. The equipment includes the interface with the communication channel.

Smart Grid: Different Components

- *Substation automation (SA)*: Deployment of substation and feeder operating functions and applications ranging from supervisory control and data acquisition (SCADA) and alarm processing to integrated volt/var control (IVVC) in order to optimize the management of capital assets and enhance operation and maintenance efficiencies with minimal human intervention.
- *Data concentrator*: Designed primarily for IED integration and may also have limited capability for hardwired I/O.

Smart Grid: Different Components

- *Distributed network protocol (DNP3):* A non-propriety communication protocol that is designed to optimize the transmission of data acquisition information and control commands from one computer to another.
- *Demand response (DR):* It defines the consumers' behavioral change to the changing rates. It enables demand-side resources and improves the economic operation of electric power markets by aligning prices more closely with the value customers place on electric power.

Smart Grid: Characteristics

- Smart grid can simply be defined as “the grid with brain.” It is a modernized grid that enables bidirectional flows of energy
- It can use two-way communication and control capabilities that will lead to an array of new functionalities and applications.
- The smart grid will permit the two-way flow of both electricity and information.

Attributions of the good smart grid are:

- Absolute reliability of supply
- Optimal use of bulk power generation and storage in combination with distributed resources and controllable/dispatchable consumer loads to assure lowest cost
- Minimal environmental impact of electricity production and delivery
- Increase in the efficiency of the power delivery system and in the efficiency and effectiveness of end use
- Resiliency of supply and delivery from physical and cyber-attacks and major natural phenomena (e.g., hurricanes, earthquakes, and tsunamis)
- Assuring optimal power quality for all consumers who require it
- Monitoring of all critical components of the power system to enable automated maintenance and outage prevention

Needs of Smart Grid

- Centralized, bulk generators, mainly coal and natural gas with very low energy efficiency (only 30%)
- Responsible for 40% of human-caused CO₂ production
- Controllable generation and predictable loads
- Limited automation and situational awareness
- Lack of customer-side data to manage and reduce energy losses

Functions of Smart Grid

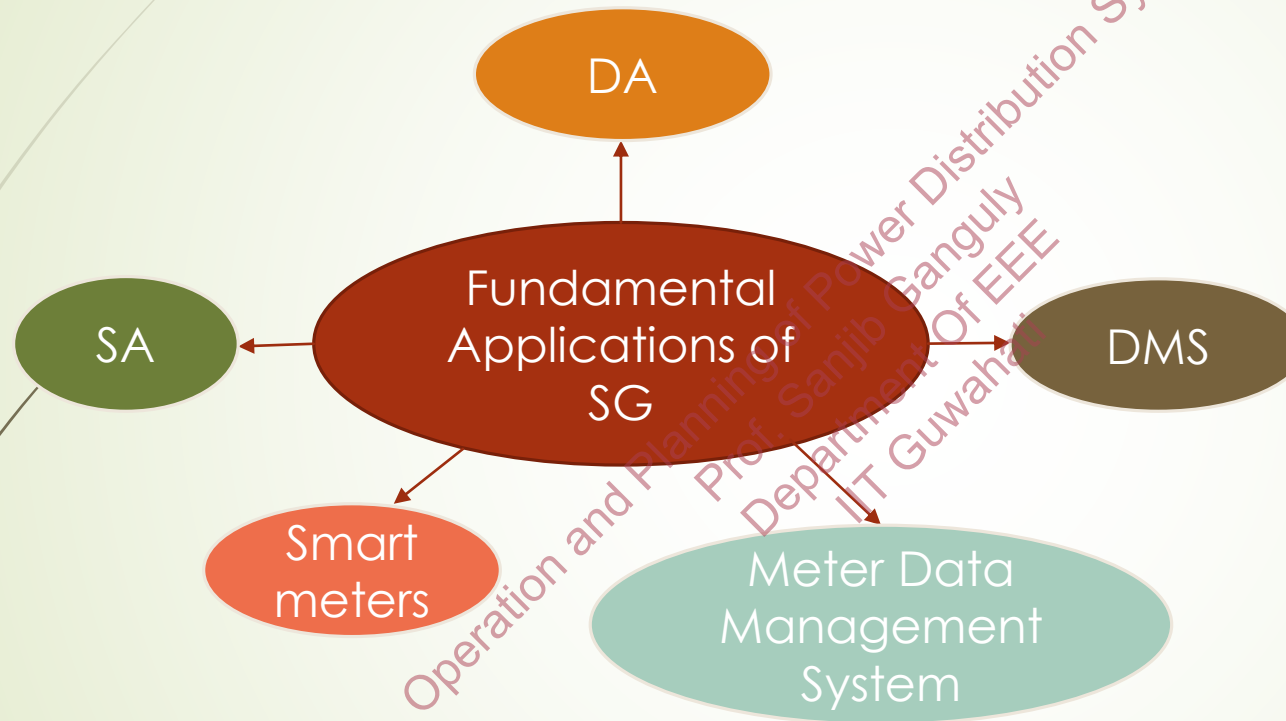
Based on a July 2009 Smart Grid Report of the United States Department of Energy, a smart grid has to have the following functions:

- Optimize asset utilization and operating efficiency:
- Provide the power quality for the range of needs:
- Accommodate all generation and storage options:
- Enable informed participation by customers
- Operate resiliently to disturbances, attacks, and natural disasters:

Comparison of the Features of the smart grid with the existing grid

Smart Grid	Existing Grid
Digital	Electromechanical
Two-way Communication	One-way Communication
Distributed Generation	Centralized Generation
Network	Hierarchical
Sensors throughout	Few sensors
Self-monitoring	Blind
Self-healing	Manual restoration
Adaptive and islanding	Failures and blackouts
Intelligent customer metering	Old-fashion customer metering
Remote checking/testing	Manual checking/testing
Pervasive control	Limited control
Many customer choices	Few customer choices

Smart-Grid: Fundamental Building Blocks

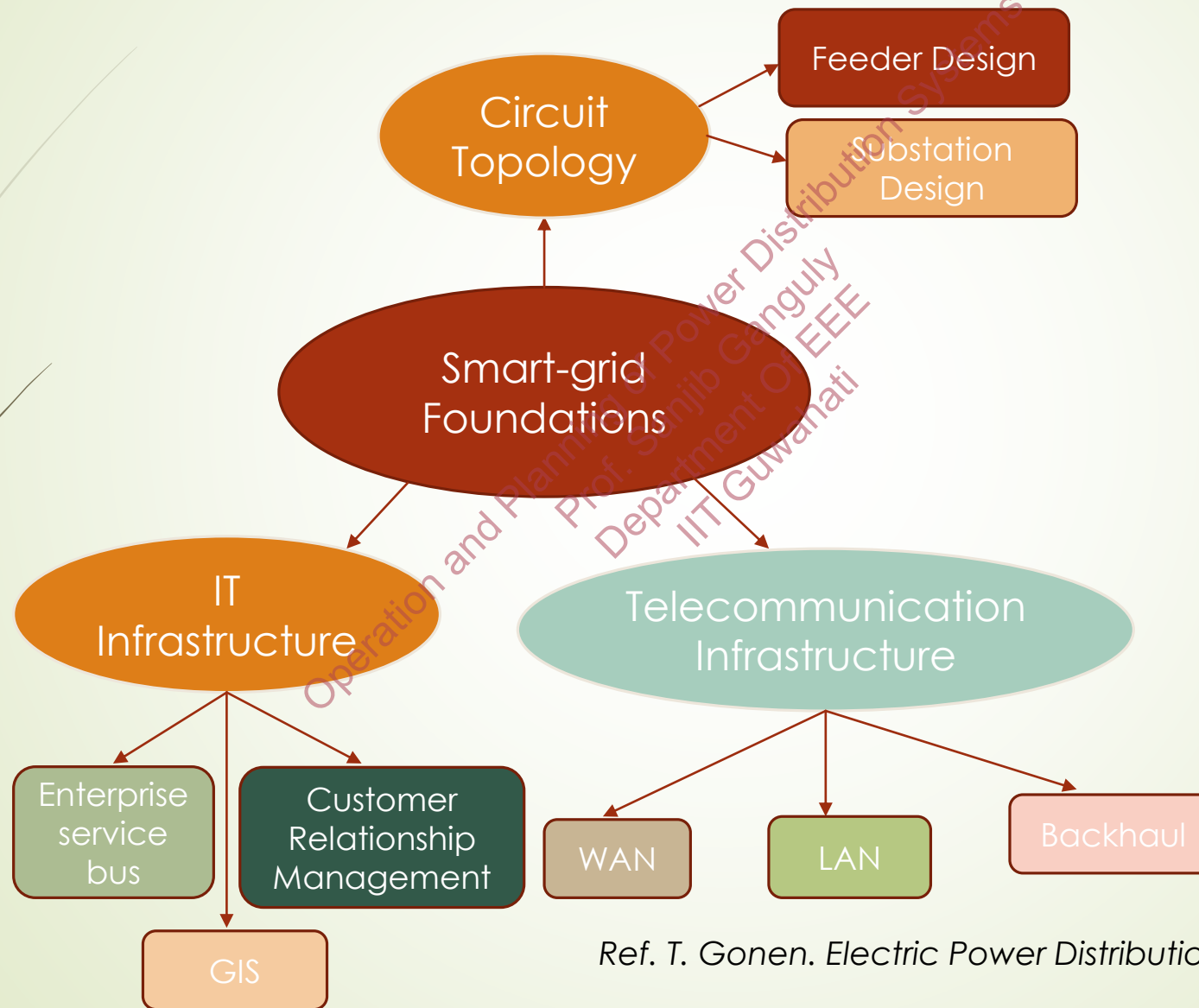


SG: Smart Grid

DA: Distribution Automation

DMS: Distribution management system

Smart-Grid: Fundamental Building Blocks



GIS: Geographical information system

Distribution Automation: IEEE Definition

- “A system that enables an electric utility to remotely monitor, coordinate, and operate distribution companies in real-time mode from remote locations.”
- The automation also includes the distribution system monitoring and automated metering infrastructure (AMI).

Distribution Automation (DA): Benefits

- Released capacity
- Reduced losses
- Increased service reliability
- Extension of the lives of equipment
- Effective utilization of assets

Distribution Automation (DA): Drivers

- Worldwide energy consumption is increasing due to population growth and increased energy use per capita.
- Increased emphasis on system efficiency, reliability, and quality
- Need to serve increasing amounts of sensitive loads
- Need to do more with less capital expenditure
- Performance-based rates
- Increasing focus on renewable energy
- Availability of real-time analysis tools for faster decision making

Distribution Automation: Control Functions

- Discretionary load switching
- Peak load pricing
- Load shedding
- Cold load pickup
- Load reconfiguration
- Voltage regulation
- Transformer load management (TLM)
- Feeder load management (FLM)
- Capacitor control

Distribution Automation: Control Functions

- Dispersed storage and generation
- Fault detection, control, and isolation
- Load studies
- Condition and state monitoring
- Automatic customer meter reading
- Remote service connection or disconnection
- Switching operations

Distribution Automation: Tasks involved and monitoring

Distribution Automation

- ☐ MV monitoring station (post type)
- ☐ MV switch automation
- ☐ MV recloser automation
- ☐ MV regulator automation

Distribution system monitoring

- ☐ Pole-top distribution equipment monitoring
- ☐ Voltage and current sensors for overhead and underground line
- ☐ Precise fault location using wave shape information

Distribution Management System: DMS

- *Fault detection, isolation, and service restoration (FDIR)*: This is to detect a fault on a feeder section based on the remote measurements from the feeder terminal units (FTUs), to rapidly isolate the faulted feeder section, and therefore to restore service to the *healthy* feeder sections.
- *The topology processor (TP)*: This is a background, offline processor to determine the distribution network topology.
- *Optimal network reconfiguration (ONR)*: This is optimally reconfigure the distribution network to minimize network energy losses, maintain optimum voltage profile, and balance the loading conditions.

Distribution Management System: DMS

- *Integrated volt/var control (IVVC)*: This is to reduce network losses with capacitor banks, to ensure desirable voltage profile with online tap changer/voltage regulator, and to reduce peak load.
- *Switch order management (SOM)*: This provides advanced analysis and execution features to better manage all switch operations in the system.
- *Dynamic load modeling/load estimation (LM/LE)*: This is the base module in DMS to accurately estimate individual loads with the available information.
- *The dispatcher training simulator (DTS)*: This is used to simulate the effects of normal and abnormal operating conditions and switching scenarios before they are applied to the real system.

Distribution Management System: DMS

- *Short-circuit analysis (SCA)*: This is used to calculate the short-circuit current to evaluate the possible impact of a fault on the network.
- *Relay protection coordination (RPC)*: This is to manage and verify the relay settings of the distribution feeders under various operating conditions and network configurations.
- *Optimal capacitor placement/optimal voltage regulator placement (OCP/OVP)*: This is used to determine the optimal locations for capacitor banks and voltage regulators in the distribution networks.

Volt-var Control of Distribution Systems: Limitations of the Traditional Approach

- Power factor correction/loss reduction
- Monitoring of switched capacitor bank performance
- Voltage regulation problem when large DG unit is connected

The Volt-var control approach using SCADA can be a remedial measure.

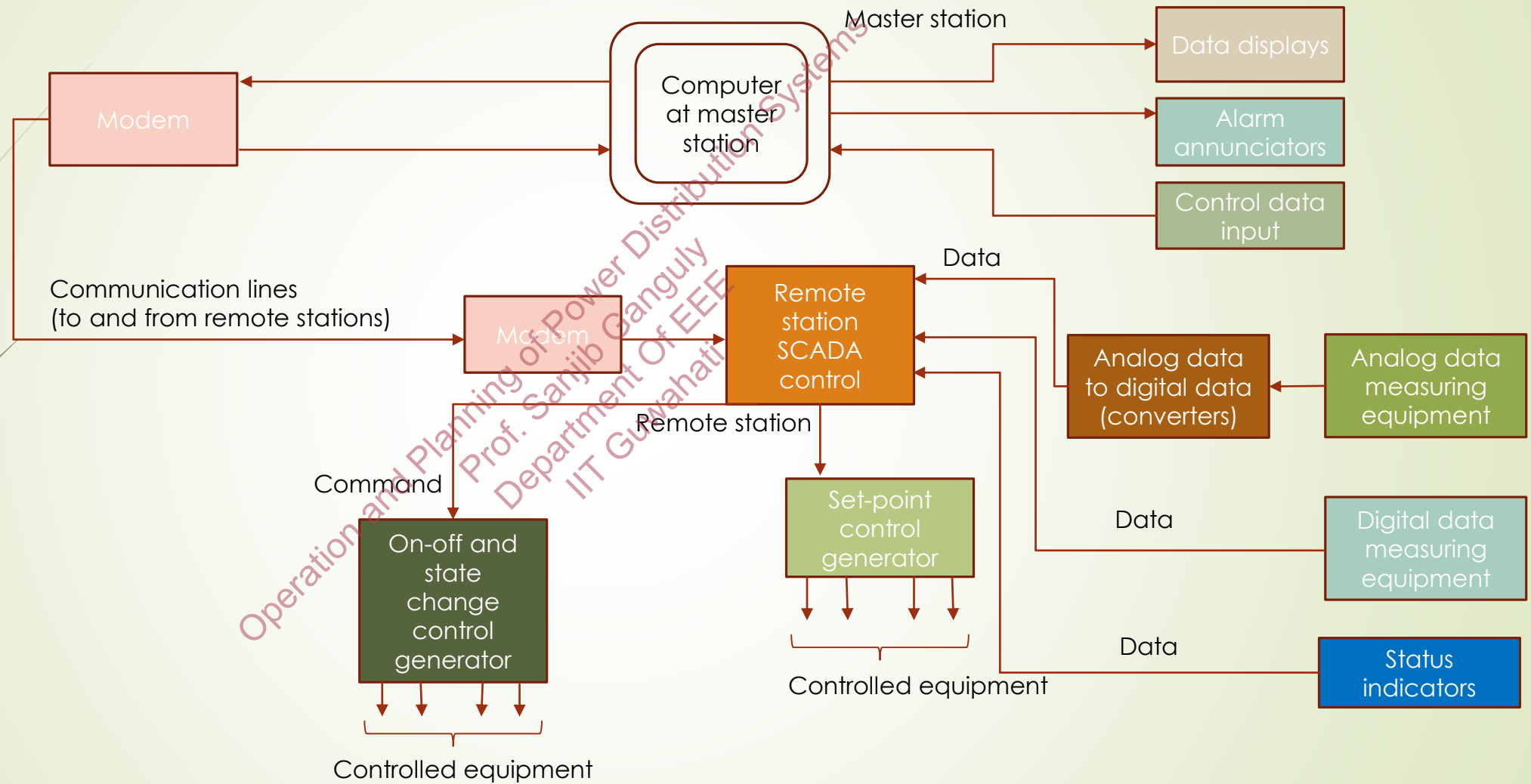
Supervisory control and data acquisition (SCADA)

- SCADA is the equipment and procedures for controlling one or more remote stations from a master control station.
- It includes the digital control equipment, sensing and telemetry equipment, and two-way communications to and from the master stations and the remotely controlled stations.

Supervisory control and data acquisition (SCADA)

- The SCADA digital control equipment includes the control computers and terminals for data display and entry.
- The sensing and telemetry equipment includes the sensors, digital to analog and analog to digital converters, actuators, and relays used at the remote station to sense operating and alarm conditions and to remotely activate equipment such as circuit breakers.
- The communication equipment includes the modems (modulator/demodulator) for transmitting the digital data and the communication link (radio, phone line, and microwave link, or power line).

SCADA



SCADA functions

- Control and indication of the position of a two- or three-position device, for example, a motor-driven switch or a circuit breaker
- State indication without control, for example, transformer fans on or off
- Control without indication, for example, capacitors switched in or out
- Set point control of remote control station, for example, nominal voltage for an automatic tap changer
- Alarm sensing, for example, fire or the performance of a non-commanded function
- Permit operators to initiate operations at remote stations from a central control station
- Initiation and recognition of sequences of events, for example, routing power around a bad transformer by opening and closing circuit breakers or sectionalizing a bus with a fault on it
- Data acquisition from metering equipment, usually via analog/digital converter and digital communication link

SCADA Planner: Tasks

- Reduction of substation design and construction costs
- Reduction of substation operating costs
- Overall lowering of power system operating costs
- Development of information for non-SCADA functions
- Utilization of existing resources and company standard for hardware, software, and database generation
- Expansion of automated operations at the subtransmission and distribution levels
- Improved customer relations

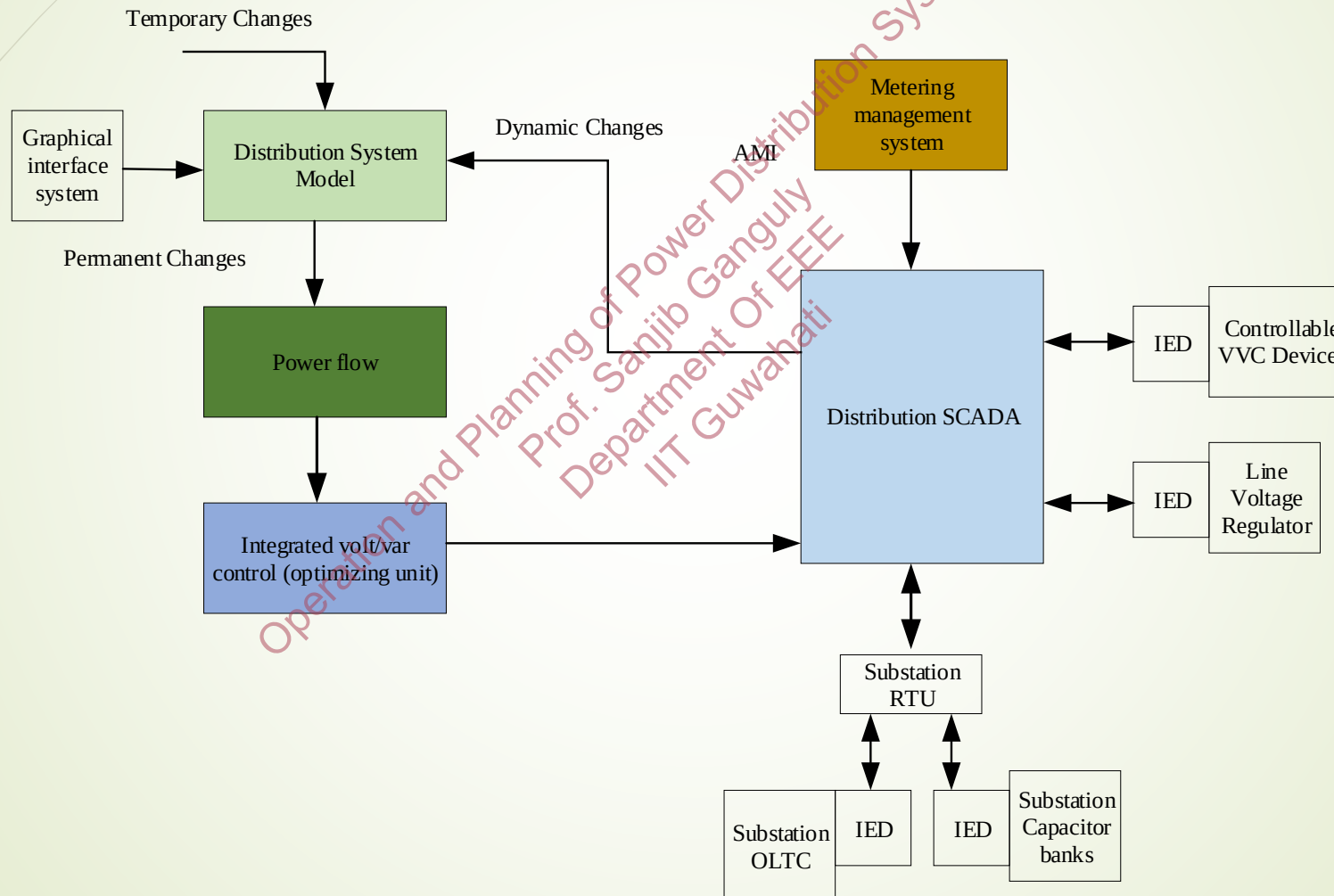
Volt-var Control of Distribution Systems: SCADA Approach

- Such Volt-var control is typically handled by two separate (independent) systems, that is,
 - ❑ by var dispatch system that controls capacitor banks to improve power factor, reduce power losses etc.,
 - ❑ by voltage control system that controls OLTCs and/or voltage regulators to reduce demand and/or energy consumption, which is also known as *conservation voltage reduction* (CVR).

Integrated volt/var control optimization

- Integrated volt/var control optimization approach (i.e., centralized approach) develops and executes a coordinated “optimal” switching plan for all voltage control devices based on an optimal power flow program to decide the plans for action.
- In the process, it achieves utility-specific objectives as well, which include (1) minimizing power demand in terms of total customer demand and distribution system power losses, (2) minimizing “wear and tear” on the control equipment, and (3) maximizing revenue that is the difference between energy sales and energy prime cost.

Integrated volt/var control optimization



Substation Automation: Controllers

- The substation controller is basically a computer system designed to operate in a substation environment. It consists of the following:
 - ❖ *Data processing applications*: These software applications provide various users access to the data of the substation controller in order to provide instructions and programming to the substation controller.
 - ❖ *Data collection applications*: These software applications provide the access to other systems and components that have data elements necessary for the substation controller to perform its functions.
 - ❖ *Control database*: All data reside in a single location, whether from a data processing application, data collection application, or derived from the substation controller itself.

Use of SCADA in Substation Automation

- Automatic bus sectionalizing
- Automatic reclosing after a fault
- Protection of equipment in a substation
- Fault reporting
- Transformer load balancing
- Voltage and reactive power control
- Equipment condition monitoring
- Data acquisition
- Status monitoring
- Data logging

Advanced developments for Integrated Substation Automation

- *IED*: Any device incorporating one or more processors with the capability to receive or send data/control from or to an external source, for example, digital relays, controllers, and electronic multifunction meters.
- *IED integration*: Integration of protection, control, and data acquisition functions into a minimal number of platforms to reduce capital and operating costs, reduce panel and control room space, and eliminate redundant equipment and databases.
- *Substation automation (SA)*: Deployment of substation and feeder operating functions and applications ranging from SCADA and alarm processing to IVVC in order to optimize the management of capital assets and enhance operation and maintenance efficiencies with minimal human intervention.

Substation Automation: Tasks of IED

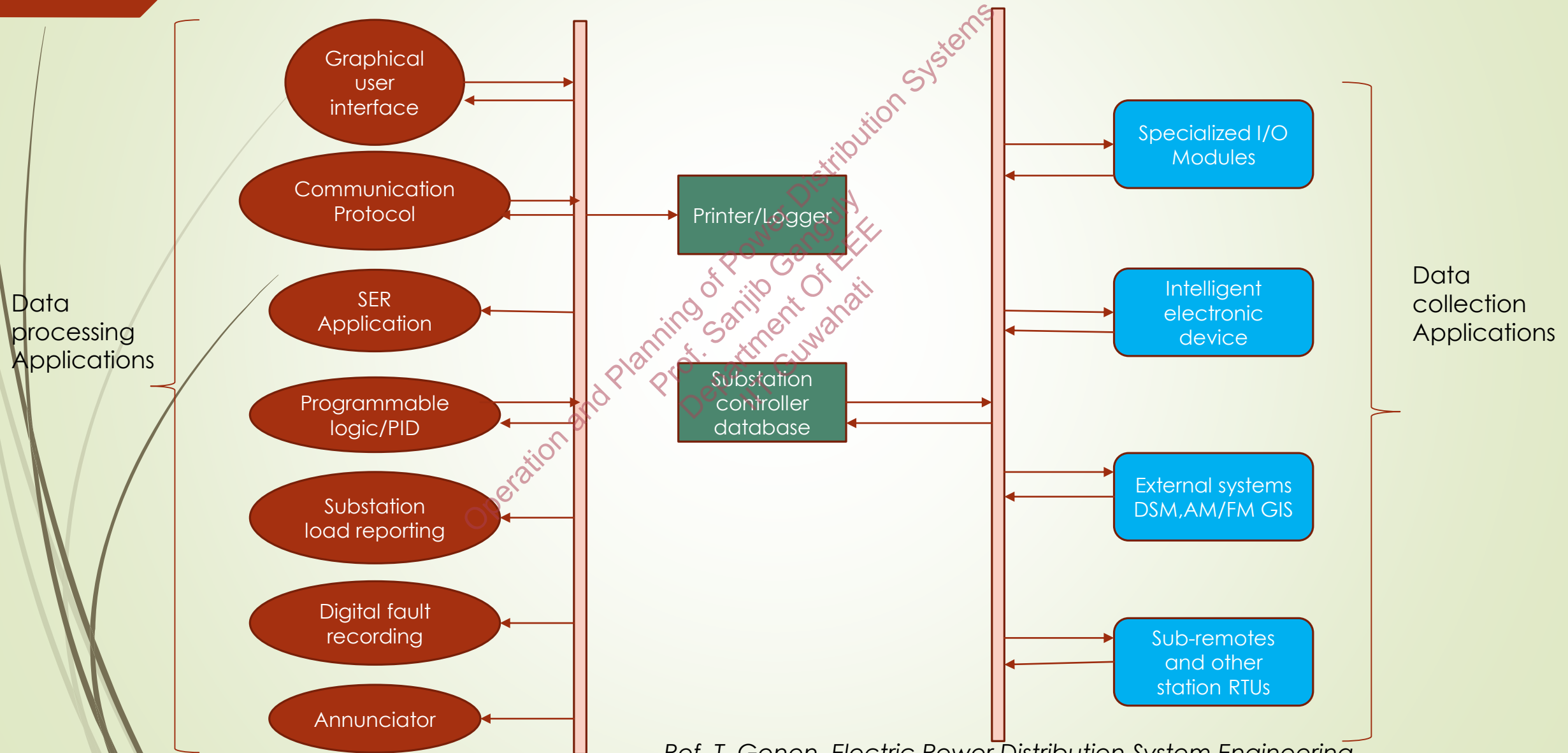
- Integration of multiple functions into single equipment
- Self-check and diagnostics,
- Communication interfaces,
- The ability to store historical data,
- Integrated RTU input/output (I/O)
- Eliminated the redundant equipment, as multiple functions were integrated into a single piece of equipment.

For example, when interfaced to the potential transformers and current transformers of an individual circuit, the IED could simultaneously handle protection, metering, and remote control.

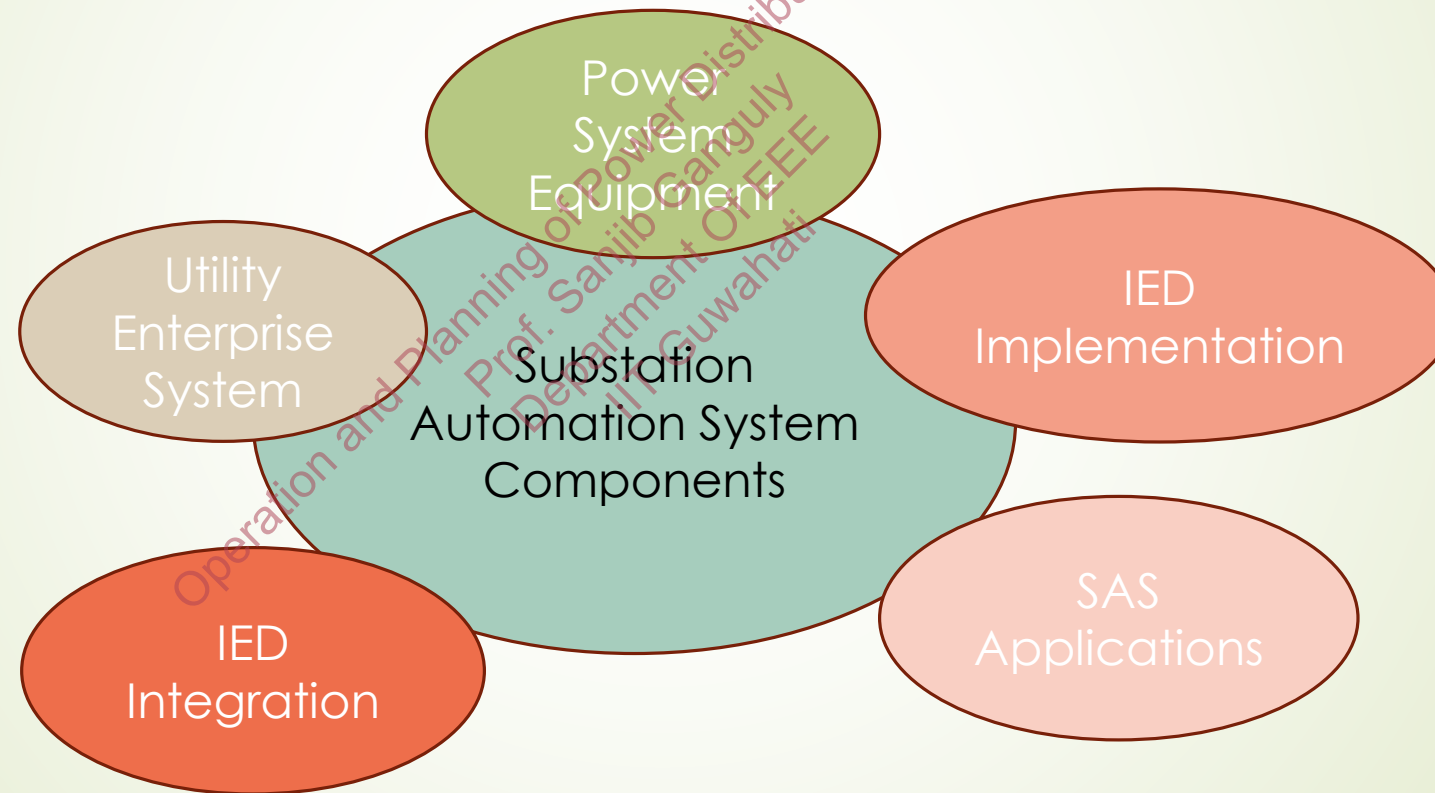
Research on IEDs

- Development of integrated single piece of equipment based on microprocessor-based device with a communication port which includes protection relays, meters, RTUs, programmable logic controllers (PLCs), load survey and operator-indicating meters, digital fault recorders, revenue meters, and power equipment controllers of various types.
- IEDs into a single integrated substation control which can lead to further streamlining of redundant equipment, as well as reduced costs for wiring, communications, maintenance, and operation, and improved power quality and reliability.

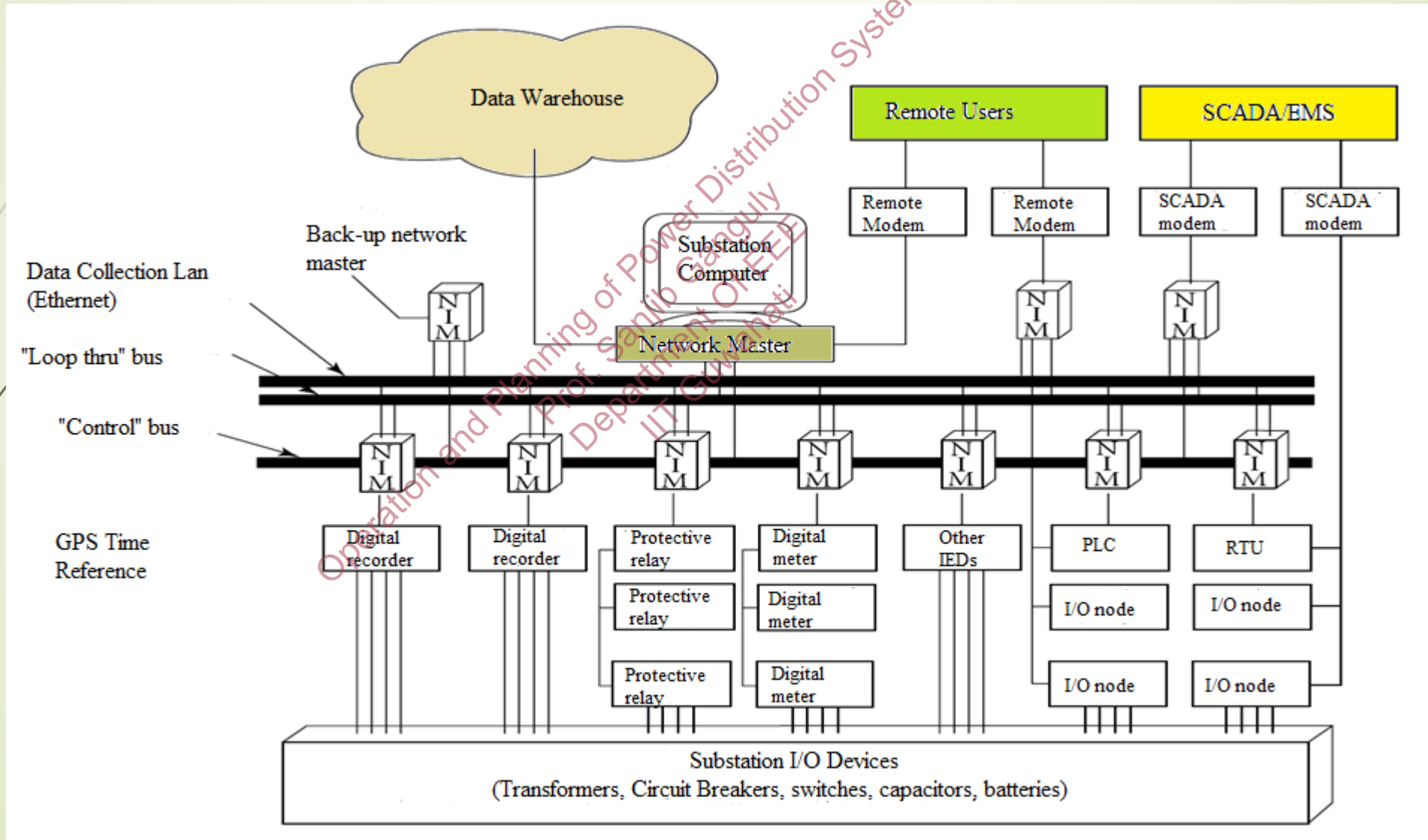
Substation Controller



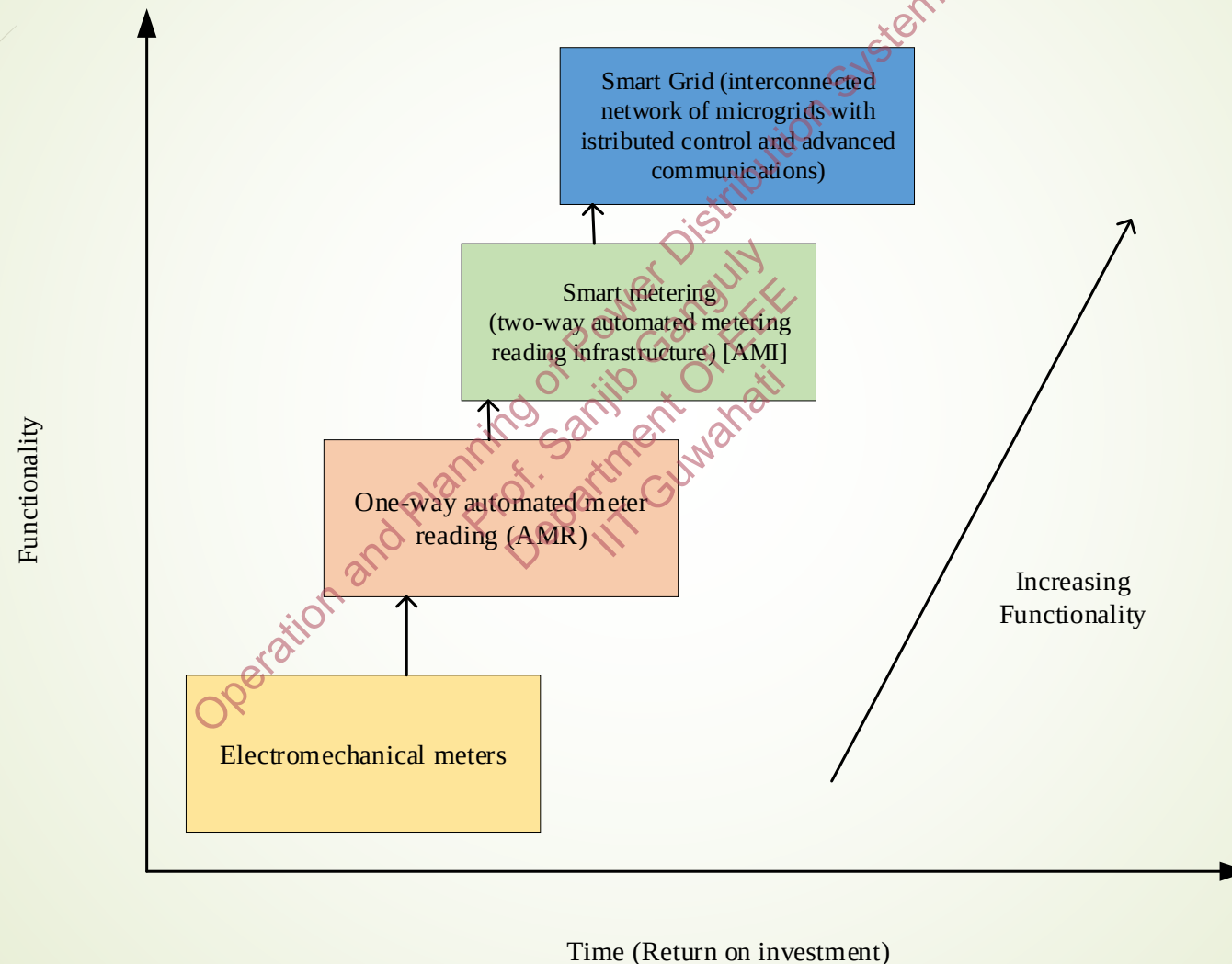
Substation Automation System



Substation Automation System



Evolution of Smart Grid: Metering System

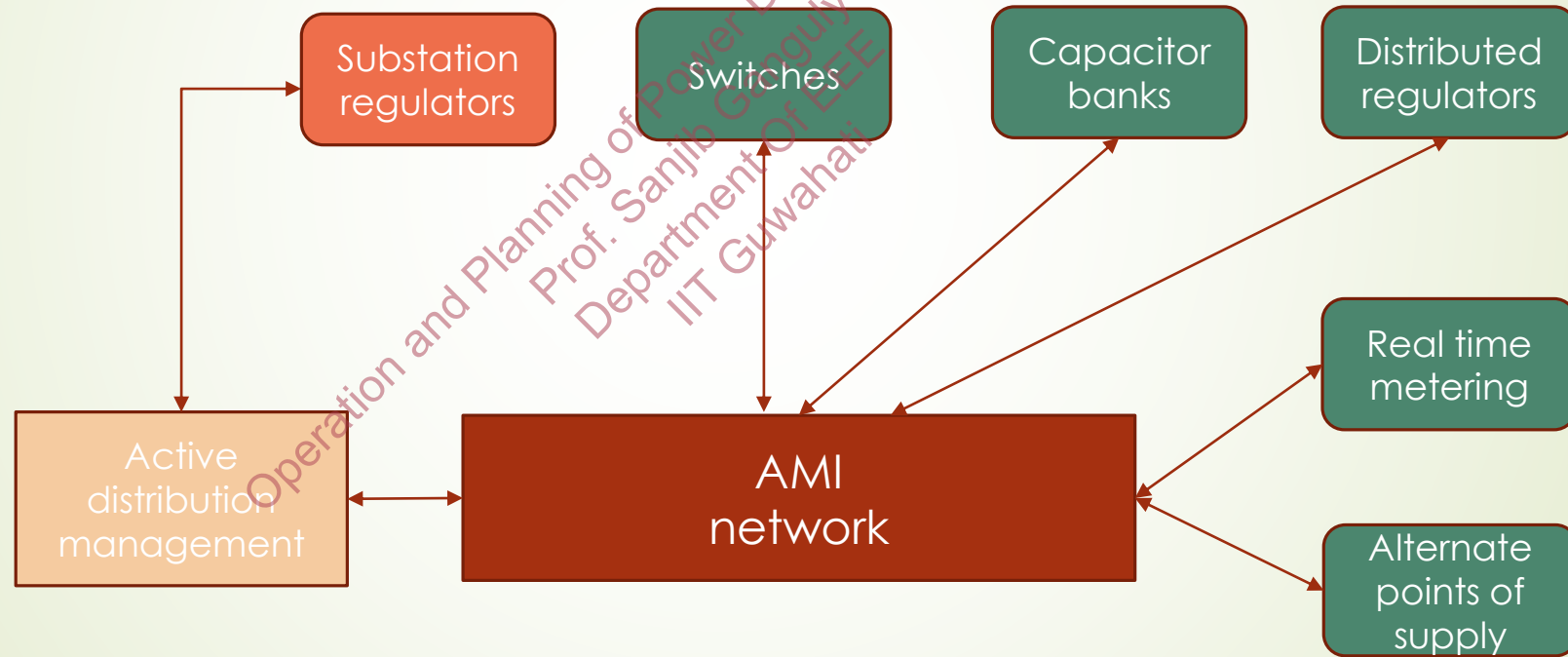


Ref. T. Gonen. *Electric Power Distribution System Engineering*

Automated metering infrastructure (AMI)

- By using AMI, utilities can reach to their goals in load management and increased revenues.
- With AMI technology, power companies not only can collect instantaneous information about individual and aggregated demand but can also modify the energy consumption, as well as implement their cost-cutting measures.
- As a next step, the smart grid requires to leverage the AMI infrastructure and implement its distribution command-and-control strategies over the AMI backbone.

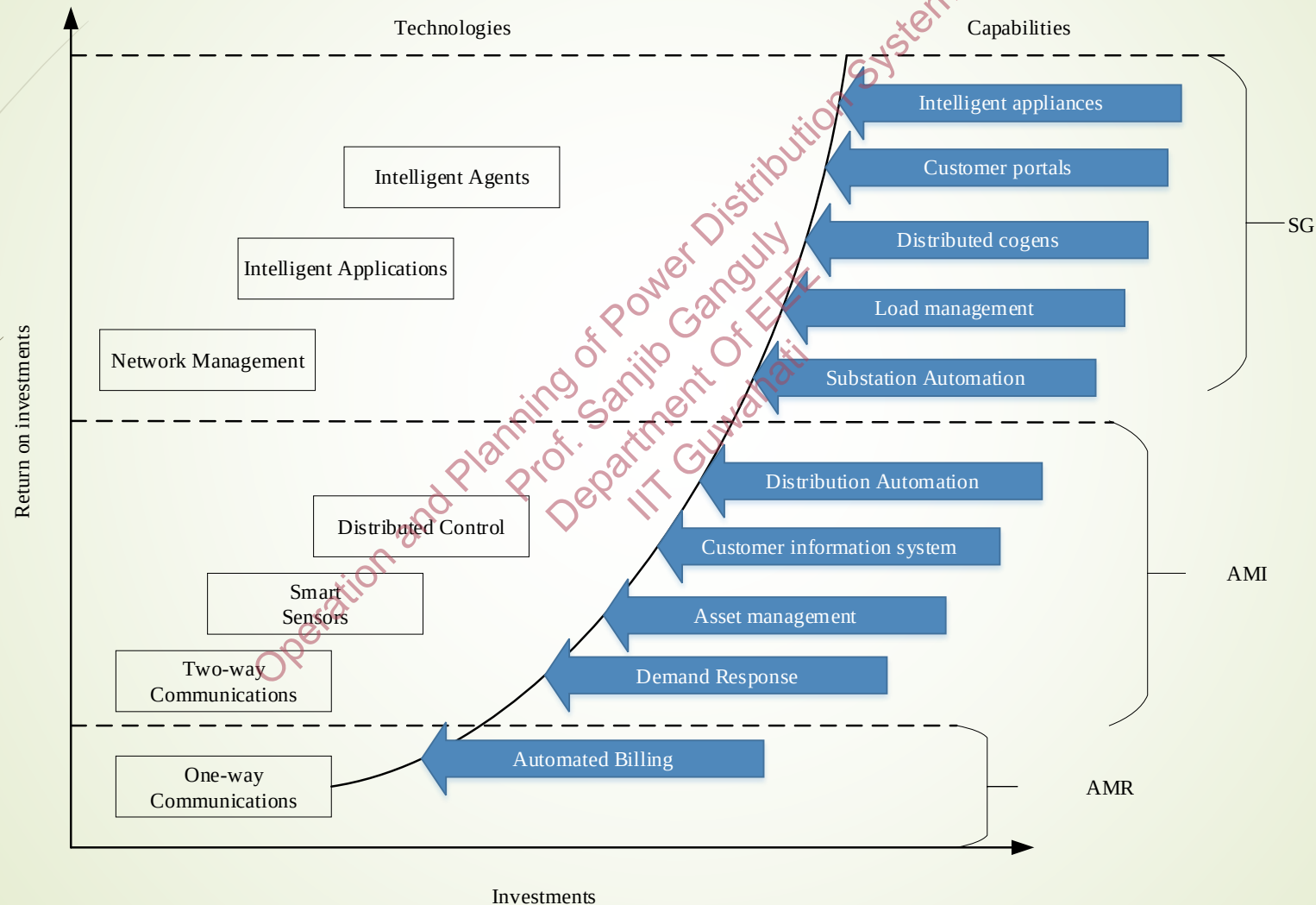
Meter Management System: Tasks of AMI



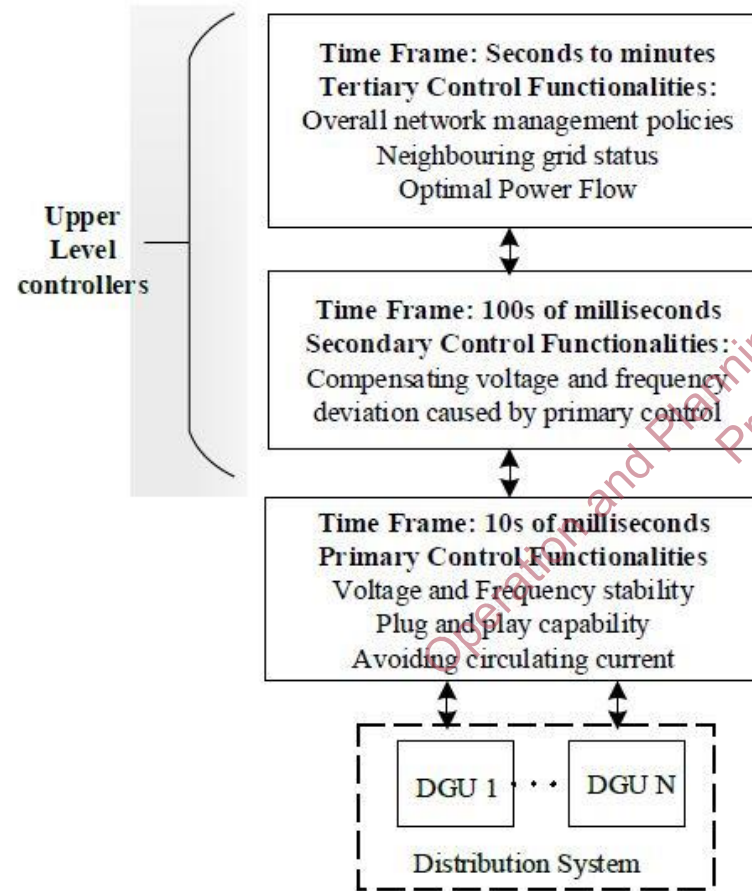
Steps to the Smart Distribution Network

- Step 1: Design information models based on overall requirements of a smart distribution system.
- Step 2: Establish substation data integration and associated applications, such as traditional SCADA and fault location.
- Step 3: Add feeder automation for selected applications. For example, automatic reconfiguration and VVC.
- Step 4: Add advanced metering integration, for example, state estimation and outage management.
- Step 5: Add integrated applications, such as energy management optimization, risk assessment, and advanced equipment diagnostics.
- Step 6: Add interface to DERs as well as islanding, advanced energy management and optimization, and real and reactive power (PQ) management capabilities.

Evolution of Smart Grid

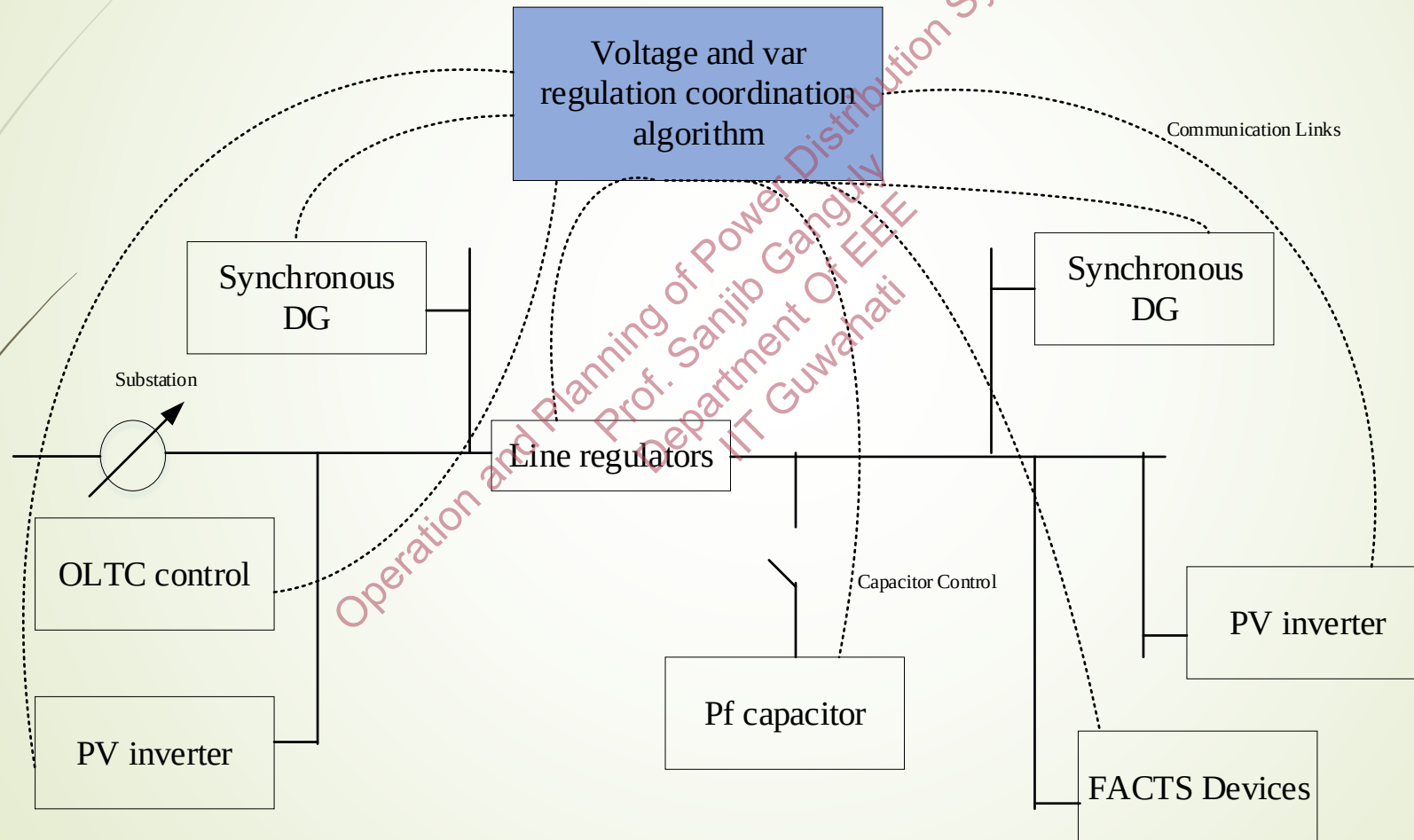


Volt/var control



Control Scheme	Centralized	Distributed	De-centralized
Computational Cost (complexity, time and space)	High	Medium	Low
Communication facilities cost	High	Medium	Low
Flexibility/Expandability	Low	Medium	High
Reliability(concerning single point of failure)	Low	High	High
Difficulty in implementation	Low	High	High

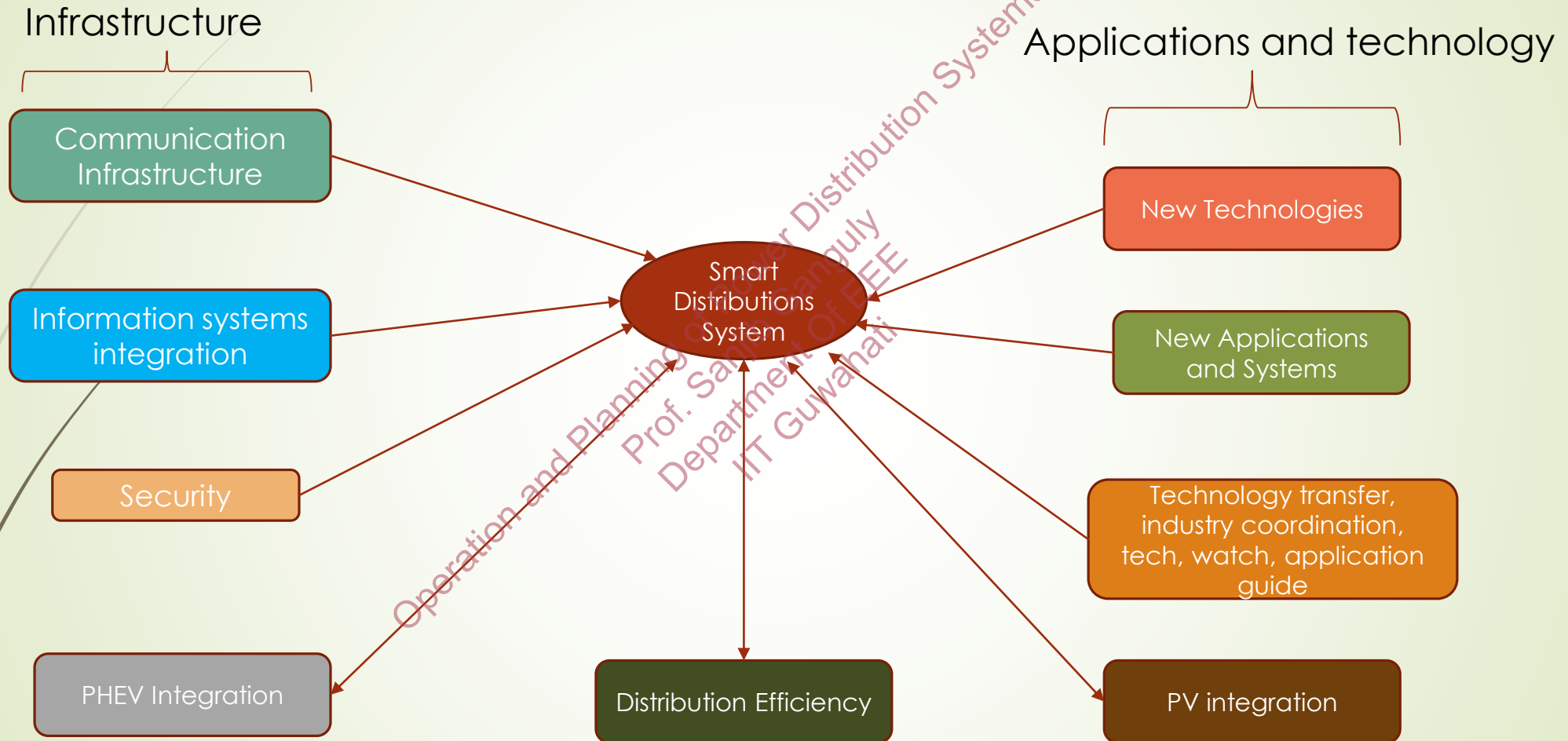
Volt/var optimization (VVO)



Challenges to the Application of Smart-Grid

- Lack of transmission capacity to meet the substantially increasing loads
- Difficulties of grid operation in a competitive market environment
- Redefinition of power system planning and operation in the competitive era
- Determination of the optimum type, mix, and placement of sensing, communication, and control hardware
- Coordination of centralized and decentralized control

Research Areas of Smart-Grid



Reference

- T. Gonen. *Electric Power Distribution System Engineering*; CRC Press, 3rd Edition, 2014.

Operation and Planning of Power Distribution Systems
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Thank You...

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