REGULATORY REQUIREMENTS FOR SMART GRID

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Smart Grid Regulations for Distribution

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Concept of Regulatory Requirements

- System Regulations are Essential for Parametric Control
- Enforcement of Rules: Effective Grid Parameters Regulation for Sustainable Power Network with almost zero failures
- Fundamentally, each segment of Power Sector needs adequate Monitoring and Control in Regulatory Framework
- Intelligent Regulatory Framework may be evolved with Digital Signatures for Electrical/Mechanical Variables depending upon Systems in Evolving Market Dynamics

Evolving Energy Market and Regulatory Framework

- Power Exchange Requires a Secure Transmission and Distribution Infrastructure with Smart Monitoring and Real Time Control for Power Flow as desired to ensure Local Electrical Parameters well within Zone of Prevailing Control Architecture
- Accordingly, Generating Systems need Smart Controls
- In Situations of Local Control Violations under changing Operational Scenario, Hierarchical Control Layers in form of Smart Controls is must for Reliability and Security

Smart Controls and Smart Grid Connectivity

- Smart Controls ensures Regulations locally well within acceptable boundary, and does not allow the relatively large perturbation to be observed at interface points of points of connectivity in Large Network Domain
- Points of Connectivity (PoC) is a generalized terminology starting from Distribution, Transmission, Generation (including Distributed Generation in upcoming RE Environment), Energy Storage and EV Charging Infrastructures with E Mobility Mission of Govt. of India

Digital Signature and Intelligent Regulatory Framework

- In large Grid with Massive Penetration of Hybrid Generation, which may include existing Classical Thermal, Hydro, upcoming Renewables (both Solar/Wind/Bio Energy) and Energy Storage along with EV Charging Infrastructure, Intelligent monitoring becomes prerequisite for Secure System Interconnection at multi-interface point of connectivity for mapping power injection pattern and load variability within Safe Grid Voltage & Frequency prevailing in New Regulations

Smart Energy Systems Environment: Smart Grid Architecture

- Smart Energy System’s Framework in Smart Grid
- Operational Improvements with Smart Controls
- Hierarchical Intelligent Layered Control & Regulations Fundamentals
- Flexible Controller Environment for Secure Grid
- Secure Communication Highway for Smart Energy Systems- An Essential Requirements for Automated Regulatory Measures as Intelligent Regulator
- Coordinated Controller Architecture

Secure Communication Highway for Smart Energy Systems

- Smart Distribution Systems need Effective Signaling for Control Injection based on Regulations in Force: Requires dedicated Communication for System Operators
- Advanced Metering Infrastructure Requires Bi-Directional Signaling: To collect, measure, and analyze energy consumption data for grid management, outage notification, and billing purposes via two way communications

Secure Communication Highway

- AMI can be leveraged to provide consumers with historical energy consumption data, comparisons of energy use in similar households, dynamic pricing information, and suggested approaches to reducing peak load via in-home displays
- For certain applications, such as near-real-time data feedback and full energy management analysis, AMI will likely be required

Technologies for on-premises networking

- The vision for Home Area Networks (HANs) is to connect the smart meter, smart appliances, electric vehicles, and on-site electricity generation or storage, both for in-home displays, controls, and data uploads, and to allow for automated modulation of energy loads during peak demand periods
- For most in-home applications, communications needs are modest. The amount of data being transferred at any one moment will likely consist only of the instantaneous electricity use of each device, measured in watts, and thus commenters state that the bandwidth needs to accomplish this will likely fall between 10 and 100 kbps per node/device

Internet Protocol (IP) for Smart Grid Communications

- ZigBee offers the advantage of being wireless while requiring very little power, and both technologies, despite being relatively low bandwidth, are cost-effective and flexible
- The communications needs of on-premises applications can be handled by low-power, short-distance technologies designed with consumer uses in mind
- A key goal for in-home networking communications may be interoperability between Smart Grid communications technologies
- Stakeholders have recommended standardizing on the use of the internet protocol (IP) for Smart Grid communications

Communications between Smart Meter and other devices on HAN

- In-home applications can leverage AMI networks, but can also exist separately from such utility-driven systems
- Both traditional meters and AMR meters can be connected to the HAN via bolt-on technologies
- For example, products may leverage a website working in concert with a WiFi-enabled sensor that reads traditional meters to allow consumers to monitor their energy use, compare their energy consumption with neighbouring homes, and learn how to improve energy efficiency
- Consumers might view their home energy consumption and electricity pricing in real-time via a wall-mounted device, control certain appliances and thermostats remotely via smartphone, and shut off conventional appliances through the use of ZigBee-connected outlets

Technologies for Hand off of Information from the Premises

- The utility network would have four tiers in the Smart Grid architecture:
- (1) The Core Backbone – the primary path to the utility data center
- (2) Backhaul Distribution – the aggregation point for neighbourhood data
- (3) the Access Point – typically the smart meter
- (4) the HAN – the home network

AMI Communication Technology

- Determining the appropriate communications technologies for AMI applications will depend on the level of AMI functionality desired
- Early AMI installations traditionally had been serviced by power line carrier (PLC) technology, which is used for relaying meter data and other internal communications over a utility’s power lines. PLC is still the most common conduit for AMI functions in rural, low-density areas, where wireless coverage is less available

Required Advanced Communication for Real Time Pricing

- To enable more advanced applications such as real-time pricing, which would bill for electricity at the current rate, a two-way communications system is required, and lower latency may be necessary as well
- The backhaul of aggregated data from an aggregation point to a utility is likely to have bandwidth requirements in the 500 kbps range. Current AMI networks may be strained by such applications
- In fact, many AMI networks only have intermittent connectivity to the utility, as data is aggregated at a neighbourhood node and only sent to the utility periodically.
- Indeed, in the opinion of many experts, backhauling real-time or near-real-time data from the billions of devices that may eventually be connected to the Smart Grid would require not only tremendous bandwidth, but also data storage capacities well beyond the current installed base, making the undertaking economically infeasible

Demand Response as Local Regulator

- One of the most common steps taken by utilities toward creating a smarter power grid has been the increasing implementation of demand response (DR). Demand response is the reduction of the consumption of electric energy by customers in response to an increase in the price of electricity or heavy burdens on the system
- Demand response can significantly reduce peak loads, Demand response programs can be implemented at both the wholesale and retail levels. Wholesale demand response programs are typically operated by independent service operators (ISO) and regional transmission organizations (RTO), while retail programs are run by utilities, Also demand response would reduce peak demand

Demand Response: Energy Management View Point

- Retail demand response can take various forms: With direct load control (DLC), customers agree to have their consumption of electricity automatically curtailed at times of peak load, via the powering down of appliances.
- A more advanced version of DR is automated DR, which allows on-premises equipment to respond to dynamic conditions on the grid, shifting load consumption in near-real-time.
- The DR device can be an energy management system or a smart appliance, the latter referred to as "prices to devices" because it sends pricing information directly to the appliance, which responds accordingly without an explicit control command

Demand Response Requirements

- Another variation of DR would have the electricity usage at the premises offloaded to distributed generation sources at the customer's location.
- A fourth variation of demand response is the delivery of dynamic pricing to the customer. With such pricing, the customer has the option to curtail electricity use manually
- The communications requirements of DR applications may vary depending on the sophistication of the system desired

Demand Response Requirements

- If next-generation DR systems work in tandem with AMI, however, the total bandwidth requirements of DR would likely be at least as high as AMI. At least as important as bandwidth for DR purposes is consistent latency
- Estimates of the latency requirements of DR fall into a wide range, from as little as 500ms to 2 seconds, and up to several minutes

Wide-Area Situational Awareness (WASA) as Regulatory Measures

- With increasing demand on the power supply system, as well as the need for improved reliability, prevention of power supply disruption is one of the key goals of the Smart Grid
- Because of the inherently interconnected and interdependent nature of the grid, improving wide area monitoring and situational awareness is necessary to achieve this objective. A disturbance in the power supply in one area can quickly translate into a widespread problem, with cascading and deleterious consequences.
- Additionally, information about the power supply in neighbouring areas can help utilities optimize the economic operation of the grid. Wide area situational awareness (WASA) refers to the implementation of a set of technologies designed to improve the monitoring of the power system across large geographic areas – effectively providing grid operators with a broad and dynamic picture of the functioning of the grid
- Synchrophasors are one of the major new wide area measurement technologies being deployed. PMUs provide precise voltage and current phasor measurements
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PMUs Role in System Regulation

- The frequency of the readings, coupled most importantly with the fact that readings from disparate locations can be time-tagged and compared to form an aggregate snapshot of the state of the power supply at any one time, enable real-time wide area monitoring of the power system.
- Data from synchrophasors are sent to phasor data concentrators, and then subsequently distributed to end users for various power monitoring applications
- Synchrophasors have a long list of specific benefits, including, among others, obviating the need for construction of additional transmission lines,100 facilitating integration of intermittent and renewable resources, and improving system modelling and planning
- Synchrophasors also assist with contingency analysis, which analyzes security through simulating the effect of removing equipment, and post-event analysis of power disturbances
- The focus of synchrophasors is widespread grid situational awareness, whereas SCADA systems will continue to be used for local monitoring and control, and synchrophasors may be used as a backup mechanism in the event that local control and management technologies fail

Communication Requirements for PMUs

- The communications requirements of synchrophasors vary depending on the nature of data being transmitted. For real-time monitoring and control, latency requirements are very low, maximum latency for these applications is 20 milliseconds
- Reliability requirements for synchrophasors are stringent
- There are several communications network technologies for networking synchrophasors. They include: fiber optics, microwave, and even broadband over powerline (BPL). The NASPInet architecture envisions a private Wide Area Network, consisting of Local Area Networks, using open network architecture "to allow the addition of future functionality and the replacement of hardware without disruption" to normal operation

Upcoming Components of Smart Grid

- Distributed Energy Resources and Storage
- Electric Transportation
- Specific challenges and opportunities presented by Electric Vehicles
- Communications needs presented by Electric Vehicles
- Distribution Grid Management: Distribution automation, Substation automation, Fleet management by Automatic Vehicle Location, Video surveillance
- Bandwidth requirements for video surveillance are high

Key Concerns of Utilities

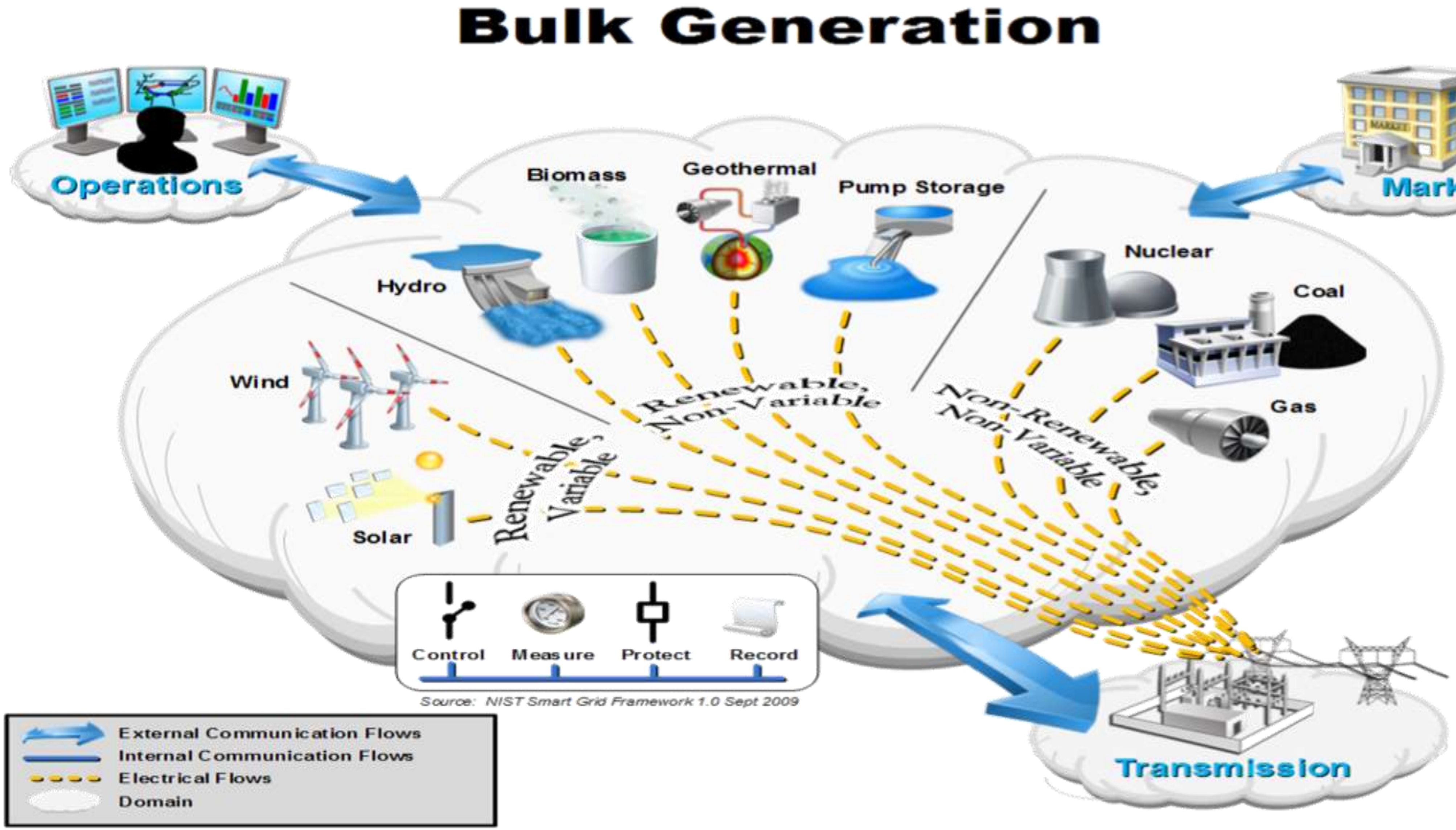
- There are several issues that cut across different functions of the Smart Grid that are of critical importance in determining how utilities will meet the communications needs of the Smart Grid. These include:
- (1) maintaining the reliability of Smart Grid communications networks through measures that ensure continuity of service
- (2) the adequacy of access to radio spectrum for wireless services to support Smart Grid technologies

- System Security and Intelligent Regulatory Architecture
- Layered Smart Grid Architecture for Secure and Sustainable Hybrid Generation
- Future Grid Regulations in Smart Grid Environment
- Renewable Energy Source (RES) Integration & Hybrid Generation: Associated System and Regulatory Requirements
- Integrated System Operation with RES- Grid Interface Challenges
- Upcoming Grid Interface Technologies- Components & Interface Devices
- Grid Intelligence and System Security

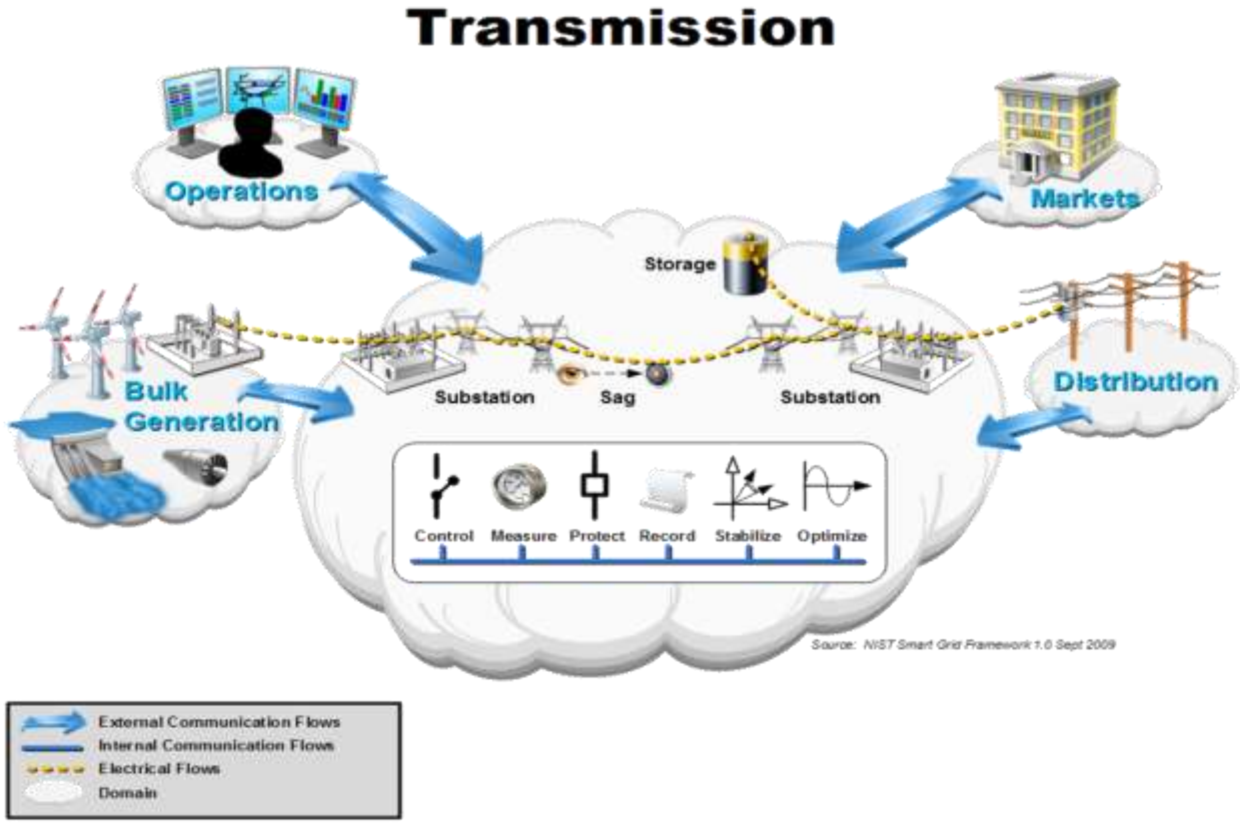
ANCILLARY SERVICES- AS CONTROLLER IN RENEWABLE ERA

- Adequate System Studies need to be conducted starting from each Distribution, Sub-Transmission and Transmission Systems
- Capacity of Existing Infrastructure needs Re-evaluation with % of Renewable Penetration
- Sectoral System Planning- An Essential Requirements for Sustainable Power Network
- Intelligent Power Controllers with IoT- Prerequisite for Coordinated Power Exchange

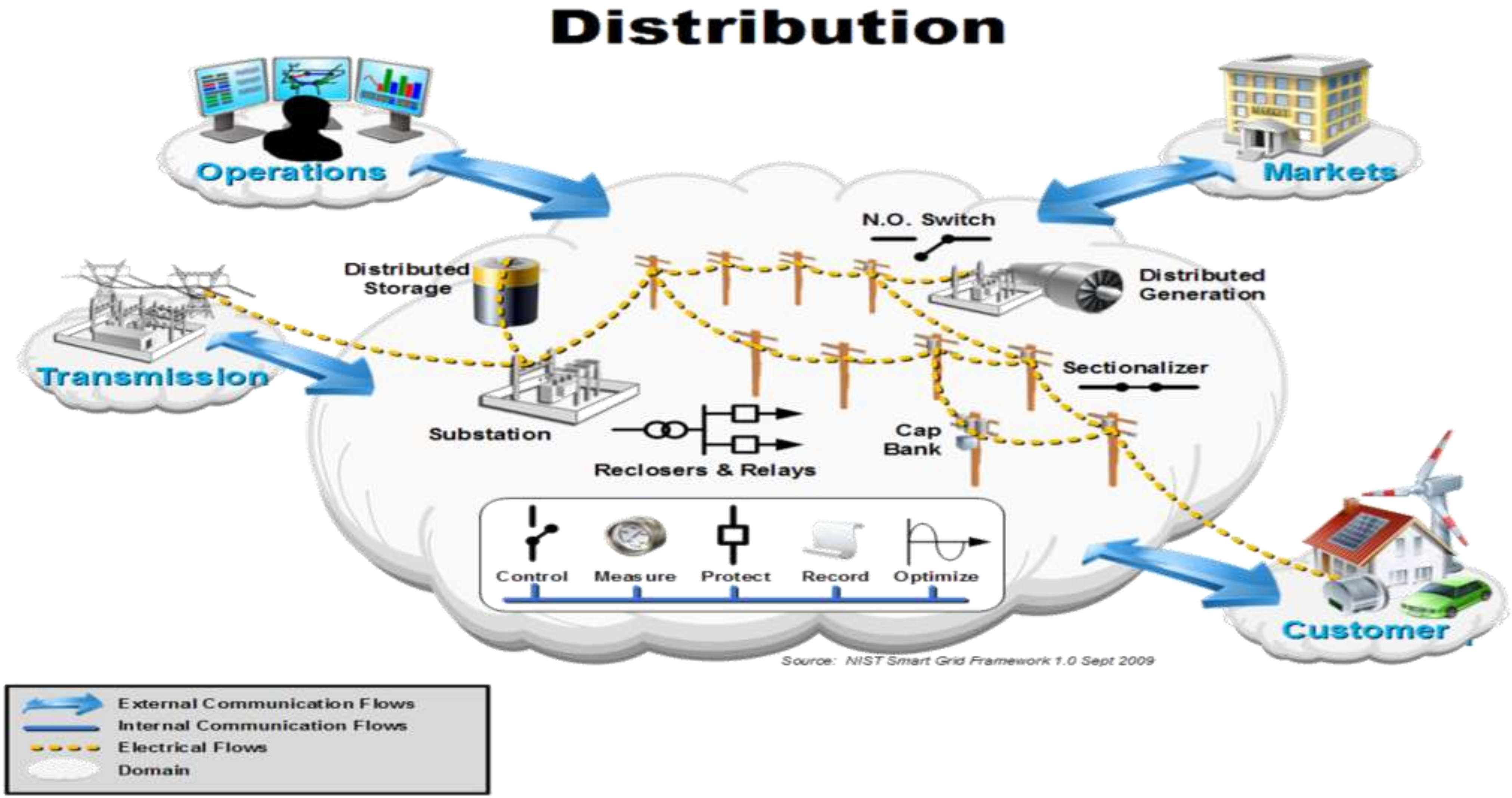
Evolving Power Sector



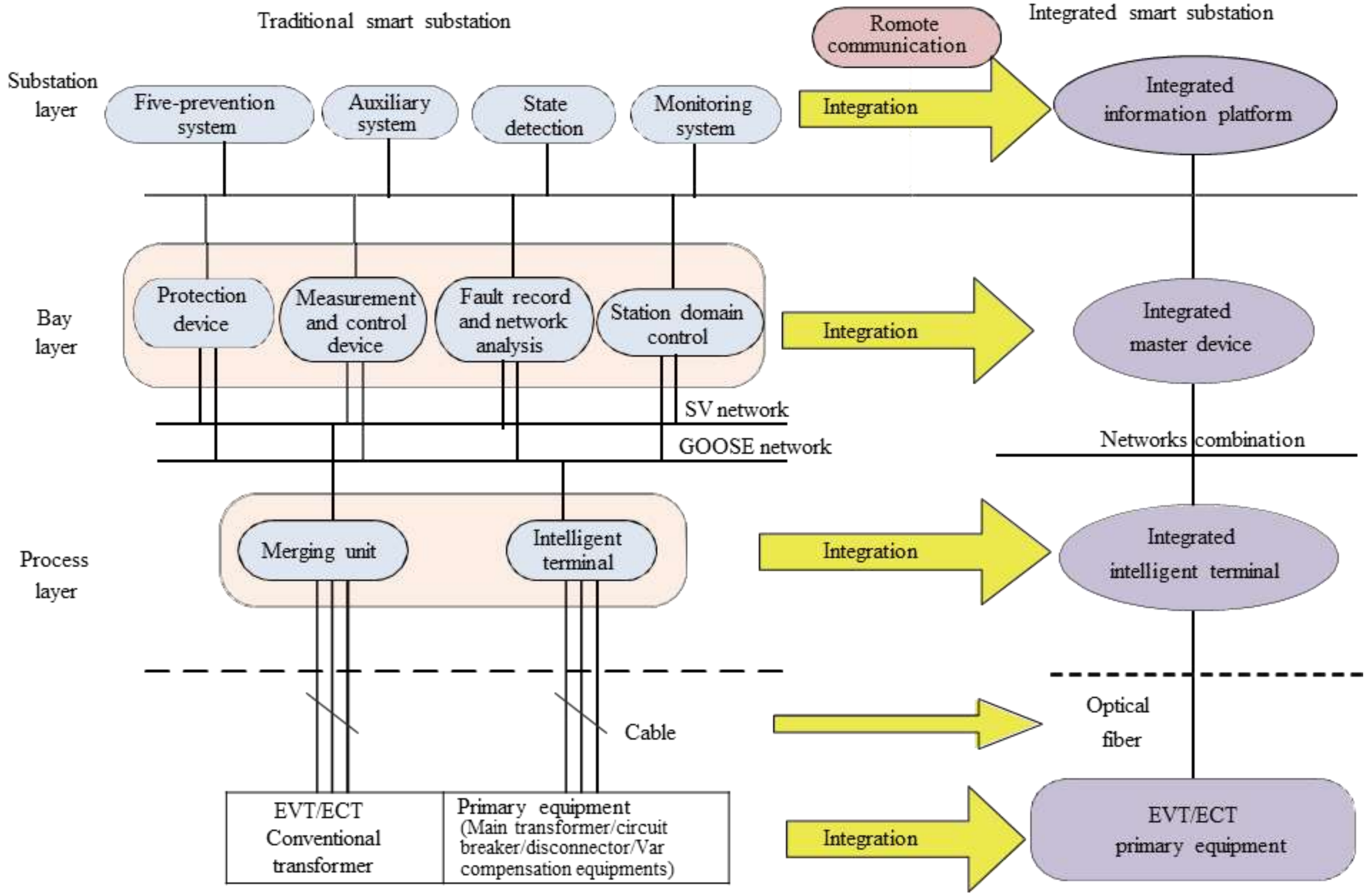
Upcoming Transmission System



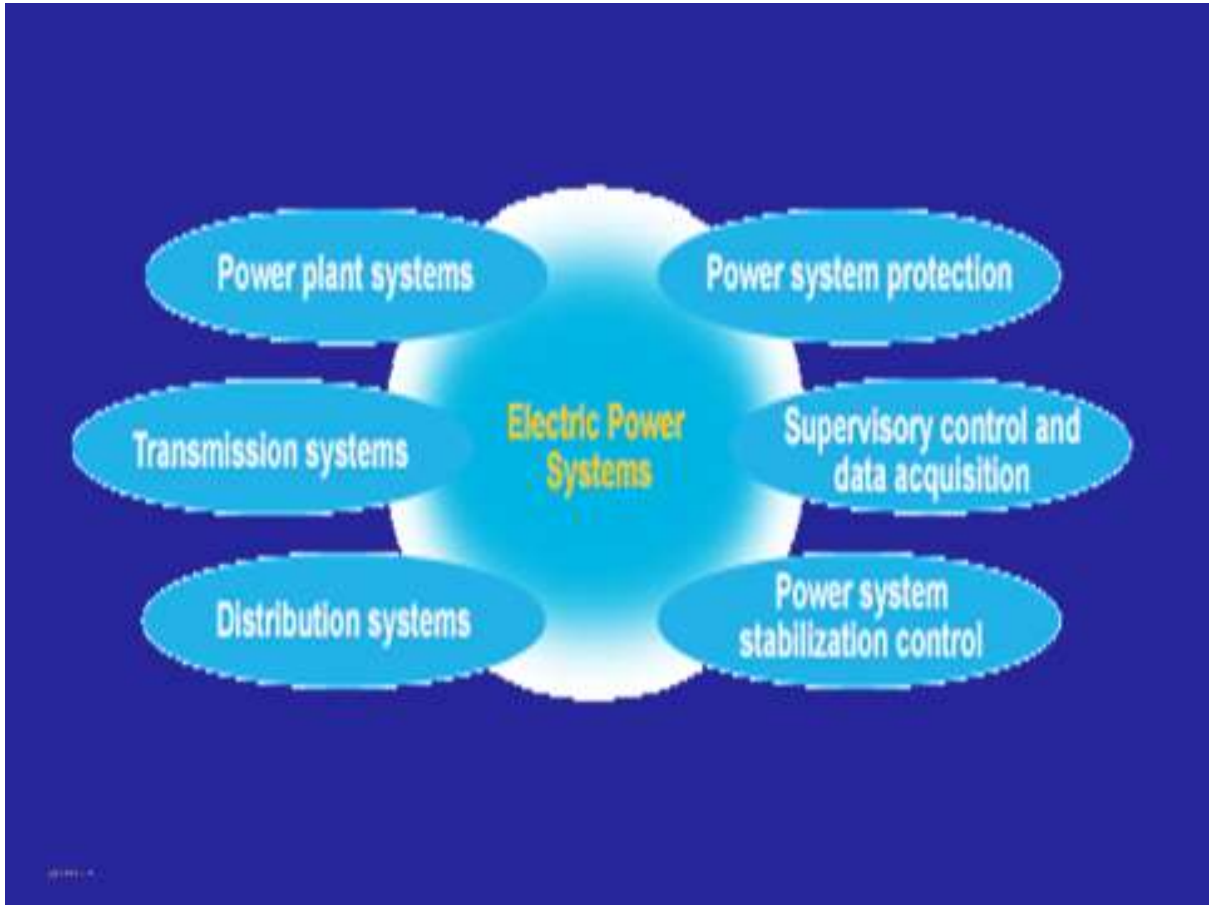
Energy Market Management

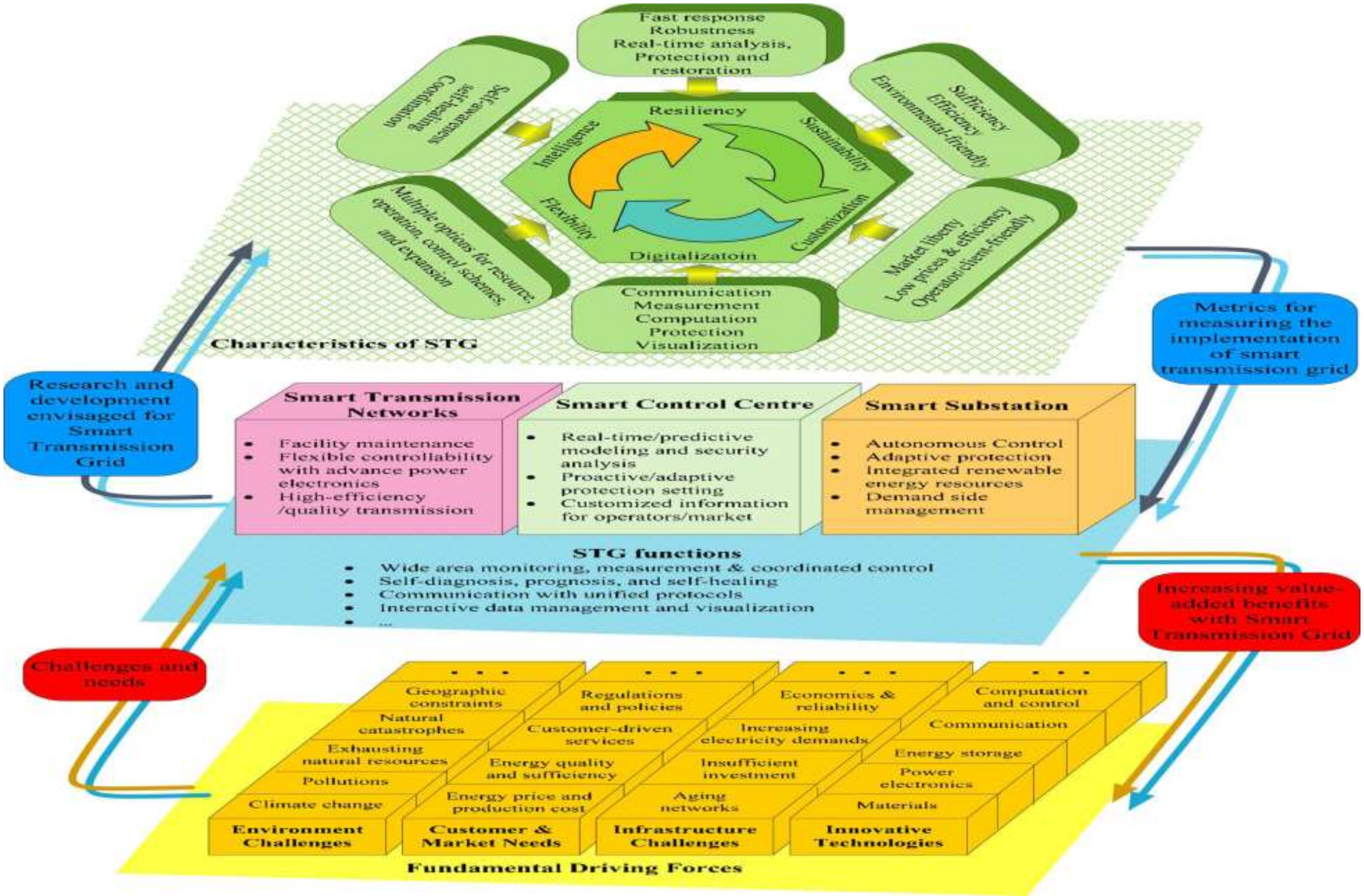


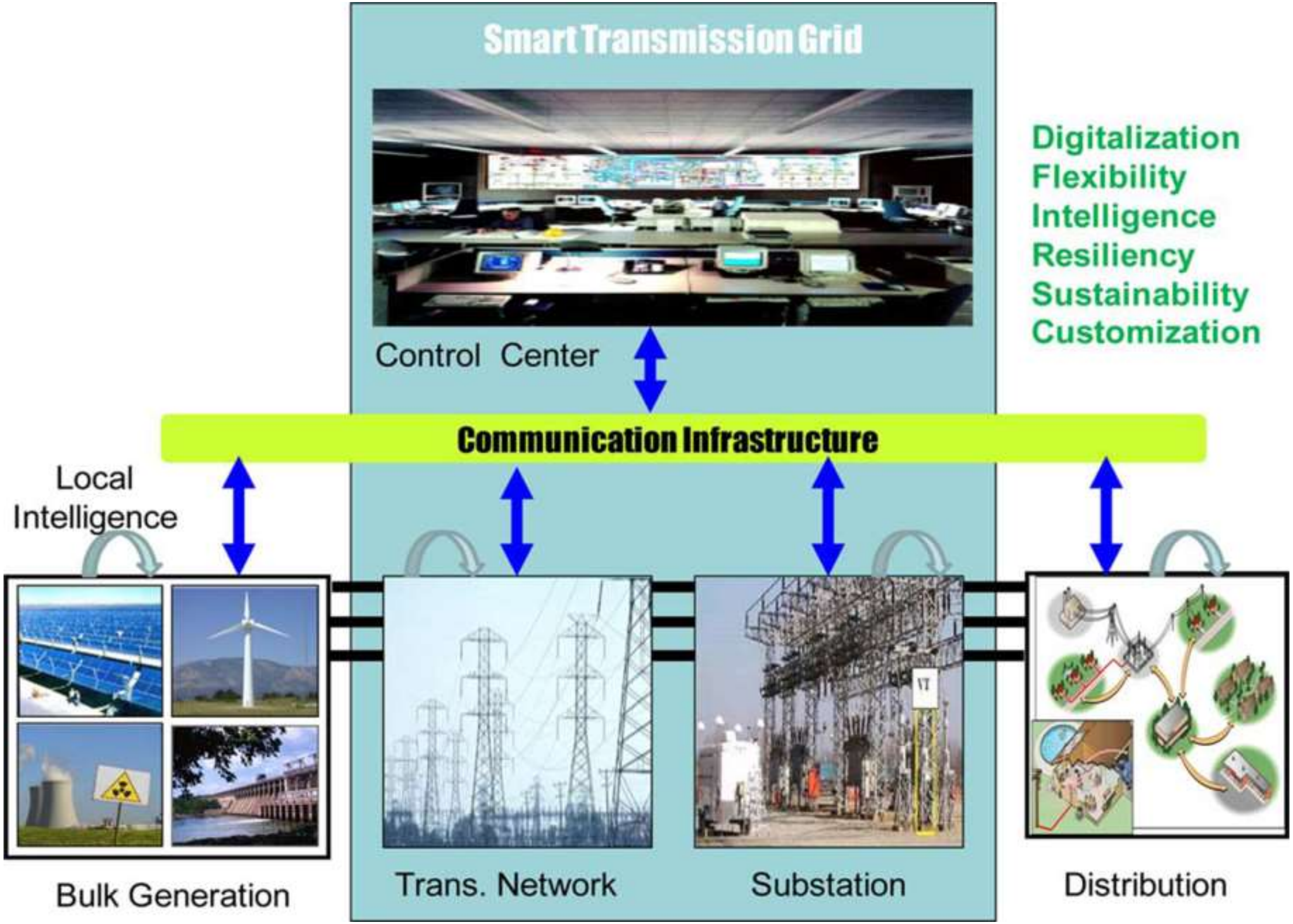
Smart Energy System



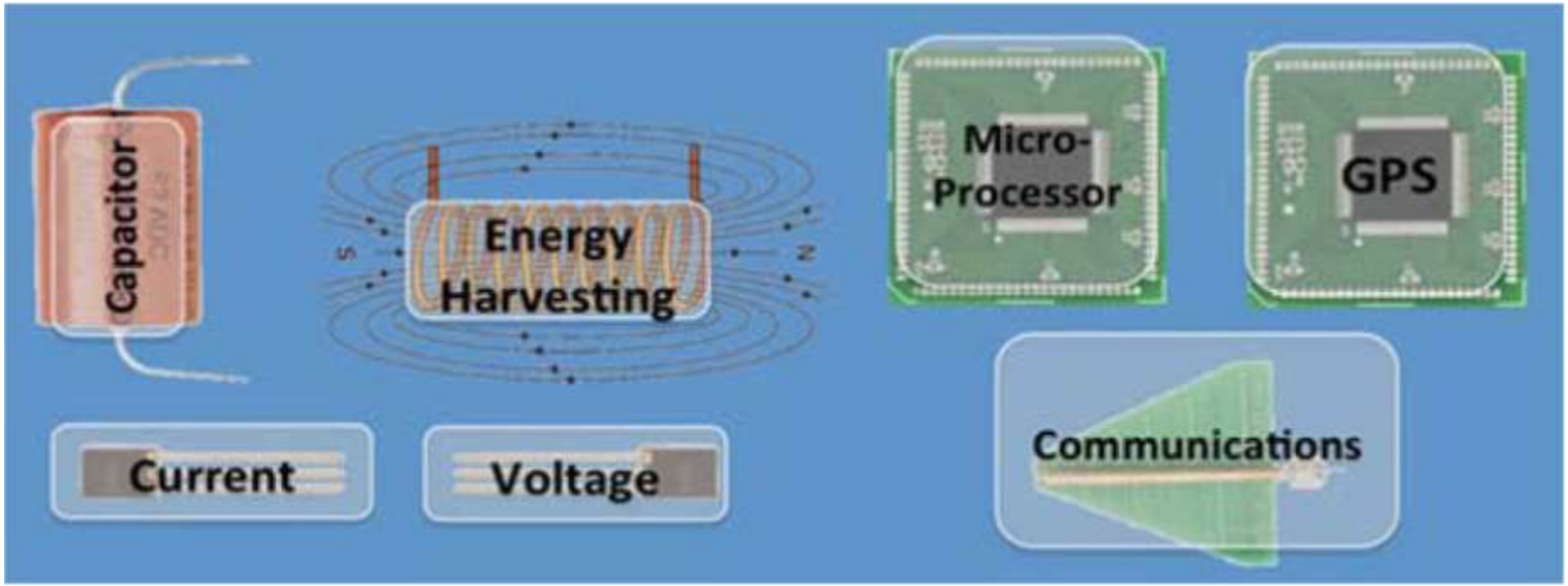
Power Network Overview

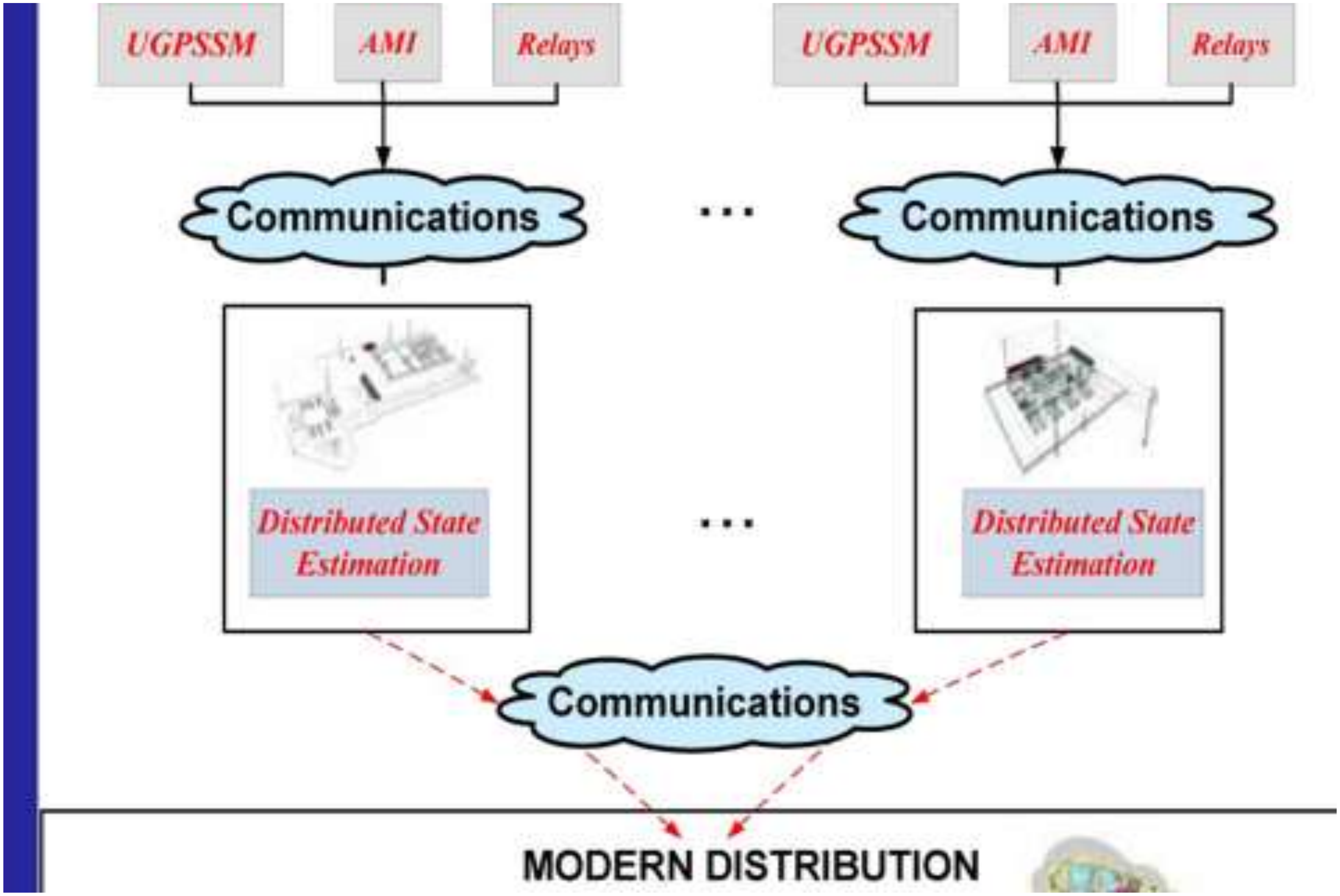


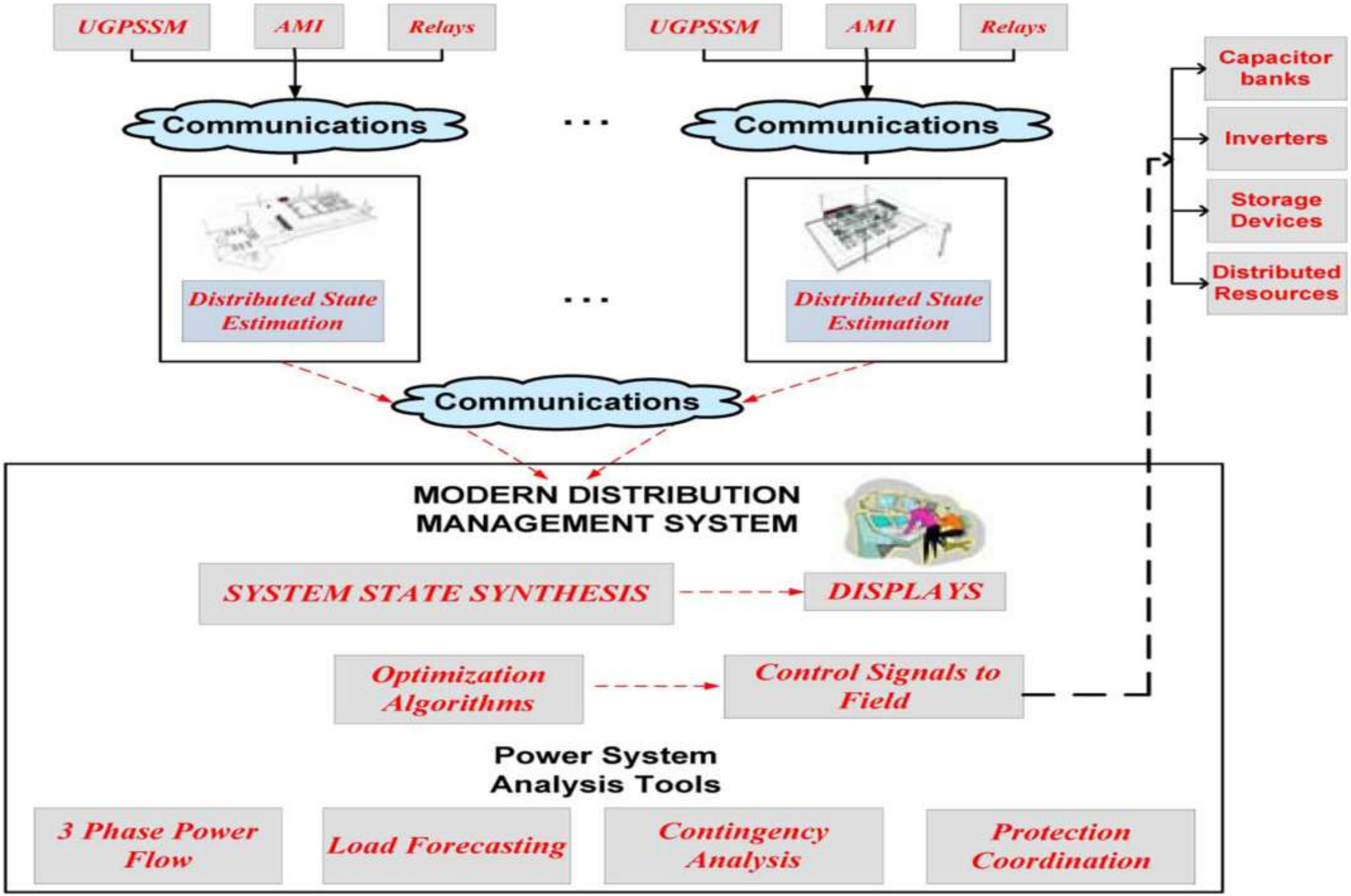

Fast response
Robustness
Real-time analysis,
Protection and restoration
Self-awareness
self-healing
Coordination
Sufficiency
Efficiency
Environmental-friendly
Resiliency
Intelligence
Sustainability
Flexibility
Customization
Digitalizatoin
Multiple options for resource, operation, control schemes, and expansion
Market liberty
Low prices & efficiency
Operator/client-friendly
Communication
Measurement
Computation
Protection
Visualization
Characteristics of STG
Research and development envisaged for Smart Transmission Grid
Metrics for measuring the implementation of smart transmission grid
Smart Transmission Networks
Facility maintenance
Flexible controllability with advance power electronics
High-efficiency /quality transmission
Smart Control Centre
Real-time/predictive modeling and security analysis
Proactive/adaptive protection setting
Customized information for operators/market
Smart Substation
Autonomous Control
Adaptive protection
Integrated renewable energy resources
Demand side management
STG functions
Wide area monitoring, measurement & coordinated control
Self-diagnosis, prognosis, and self-healing
Communication with unified protocols
Interactive data management and visualization
...
Increasing value-added benefits with Smart Transmission Grid
Challenges and needs
Geographic constraints
Natural catastrophes
Exhausting natural resources
Pollutions
Climate change
Environment Challenges
Regulations and policies
Customer-driven services
Energy quality and sufficiency
Energy price and production cost
Customer & Market Needs
Economics & reliability
Increasing electricity demands
Insufficient investment
Aging networks
Infrastructure Challenges
Computation and control
Communication
Energy storage
Power electronics
Materials
Innovative Technologies
Fundamental Driving Forces

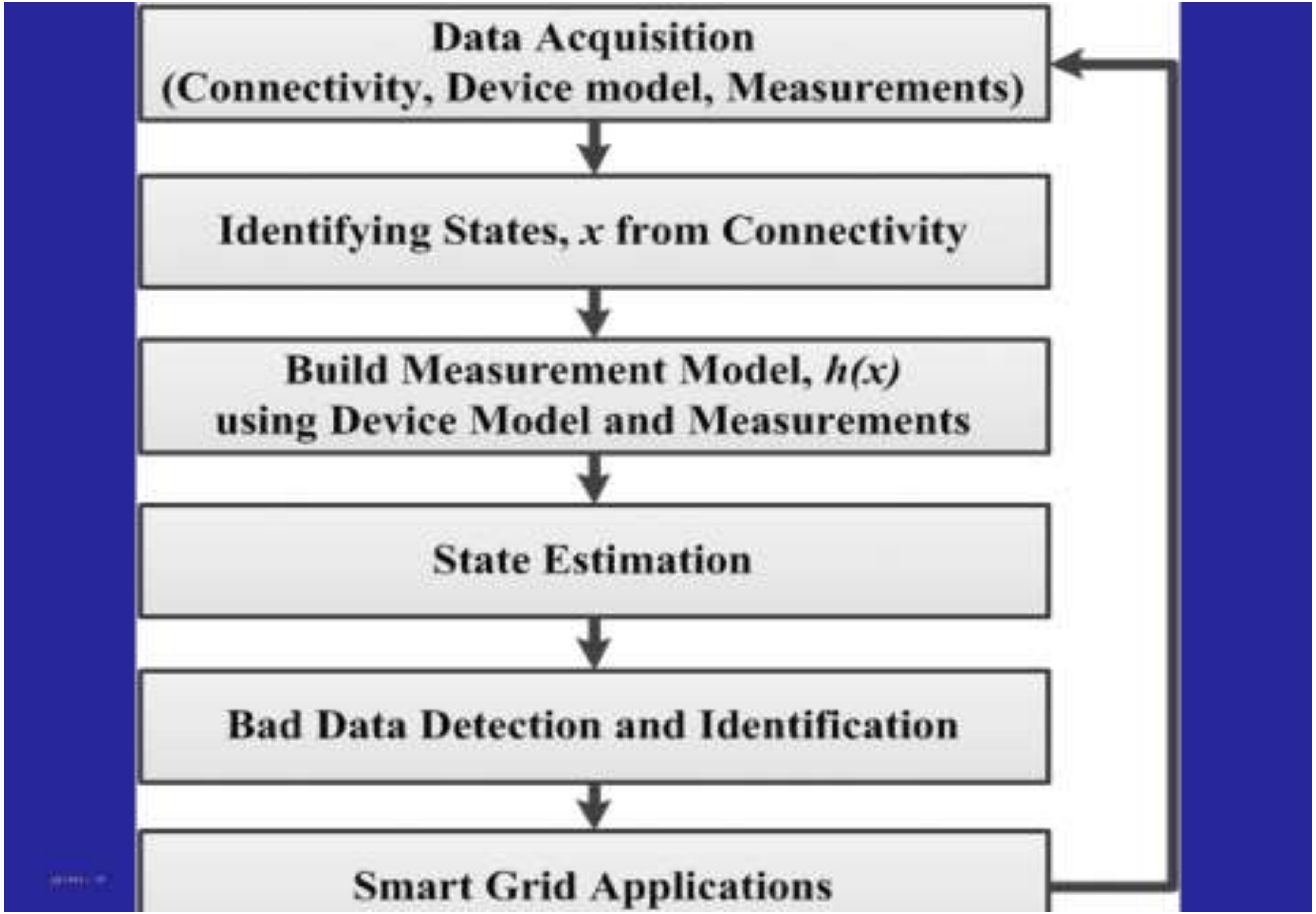

Smart Transmission Grid
Control Center
Digitalization
Flexibility
Intelligence
Resiliency
Sustainability
Customization
Communication Infrastructure
Local Intelligence
Bulk Generation
Trans. Network
Substation
Distribution

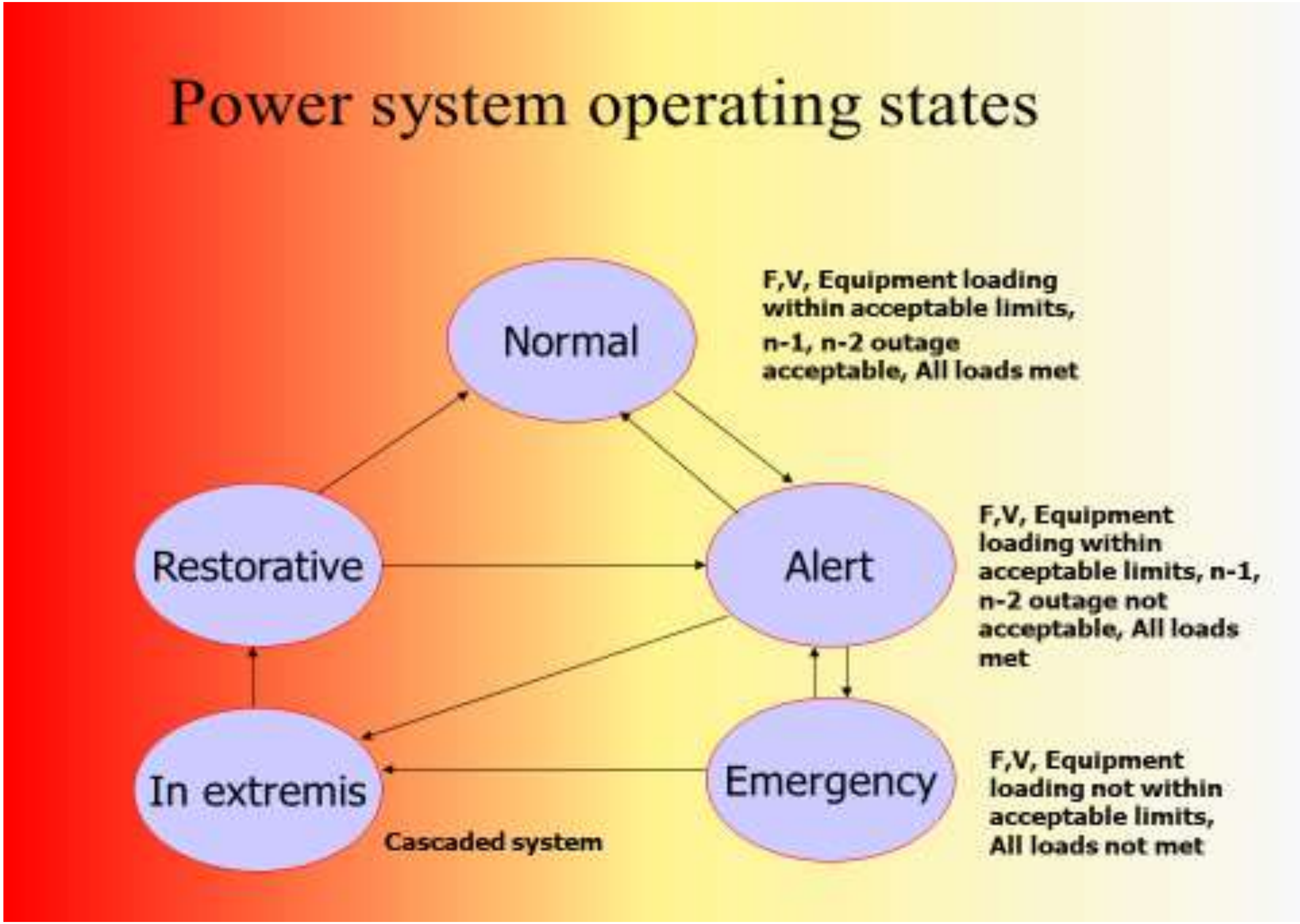
Conceptual view of self-powered GPS-synchronized, communications enabled smart meter.




UGPSSM
AMI
Relays
UGPSSM
AMI
Relays
Communications
…
Communications
Distributed State Estimation
…
Distributed State Estimation
Communications
MODERN DISTRIBUTION


UGPSSM
AMI
Relays
Communications
Distributed State Estimation
UGPSSM
AMI
Relays
Communications
Distributed State Estimation
Communications
Capacitor banks
Inverters
Storage Devices
Distributed Resources
MODERN DISTRIBUTION MANAGEMENT SYSTEM
SYSTEM STATE SYNTHESIS
DISPLAYS
Optimization Algorithms
Control Signals to Field
Power System Analysis Tools
3 Phase Power Flow
Load Forecasting
Contingency Analysis
Protection Coordination


Data Acquisition
(Connectivity, Device model, Measurements)
Identifying States, x from Connectivity
Build Measurement Model, h(x)
using Device Model and Measurements
State Estimation
Bad Data Detection and Identification
Smart Grid Applications


Power system operating states
Normal
F,V, Equipment loading within acceptable limits, n-1, n-2 outage acceptable, All loads met
Restorative
Alert
F,V, Equipment loading within acceptable limits, n-1, n-2 outage not acceptable, All loads met
In extremis
Cascaded system
Emergency
F,V, Equipment loading not within acceptable limits, All loads not met

PMUs as Smart Sensors in WAMS

- Challenges in System Operation due to ongoing Dynamical Conditions
- Proper Integration of WAMS Signal may prove Effective in Operator's Decision
- Synchrophasor Technology with PMUs may be of great help to Power Utilities in observing Grid parameters variations
- Integration of PMUs Signal for Real Time Energy Control Centres - Major Challenge in Technology
- Greater number of PMUs implies Exponential growth in size of the data and related Analytics

Grid Health Monitoring with PMUs

- Ordinarily PMU Signals in form of Phase Angle, Voltage, Current, Frequency and Rate of Change of Frequency are available
- The Overall System Health reflection in above signals may be marked preciously.
- The Most Suitable Signal's Quick Identification and associated processing at respective Energy Control Centres may help operator and also avoid excursion on Grid

PMU Signal Identification and Prioritization- An Important Role

- Conceptually Power Systems are governed by Dynamical variations and PMUs may assist in visualizing very closely states of Power Network
- Signals available as PMU output may have close interrelations, but some of the signals occurrence can be noticed as fast changing and needs deep analytics and learning methodology
- Processing of real time signals having major impact on Grid requires quick control initiation at respective end which may be of great help in System Security

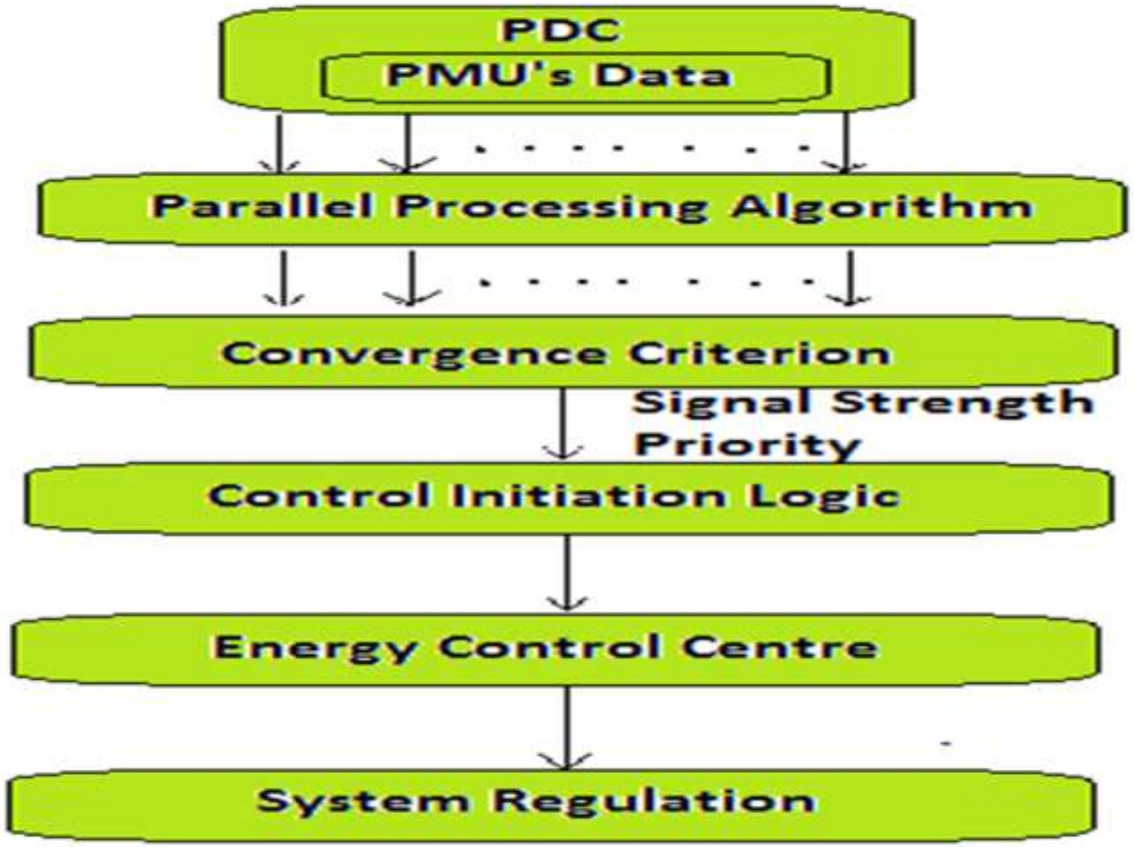
Integration of PMU Signal with Controllers/Energy Control Centres

- The most prominent and effective signal detection may provide a sound basis for control decisions initiation
- The concept of signal Prioritization involves parallel processing algorithm exploitation with suitable high speed processors (Super Computing Environment) along with very fast controllers for maintaining the security and reliability of large interconnected systems
- The Digital Signatures of respective Modules may form the basis of Regulation Violation and Intelligent Regulatory Mechanism

Data Analytics and Precise Control: An Innovative Approach for Smart Grid Regulations

- Ideally speaking the huge data emerging with deployment of PMUs may not be classically understandable by Operators' sitting in control room.
- This necessitates the deployment of parallel processing algorithm looking into virtual time requirements and afterwards decision making process with control strategy.
- Data Mining Algorithm may facilitate Data Analytics.
- This may be useful in Detecting unwanted ongoing events and also fixing the Regulatory Penalty in case of violation

Advance Intelligent Control Architecture for Evolving Smart Grid Architecture



Concept of Signal Detection

Identifies

- Concept of signal prioritization based on STREAM DATA MINING techniques

Proposes

- Novel methodology based on signal selection criterion

For initiating

- the control decision by energy control centres
- to ensure smooth system operation in real time to avoid undesirable scenario

Smart Grid Attributes

Economics

- Cost Saving from peak load reduction
- Economics
- Differed capital sending for generation, transmission & distribution investment
- Reduce Operational & Maintenance Cost
- Reduce Industrial Consumer cost

Services

- Improved reliability & Power quality
- Reduction in AT&C losses
- Efficient Power delivery
- Improved Grid security
- Demand side management and Demand response

Environmental

- Reduction in CO2 Emission and Green House Effect
- Increase the penetration of clean energy with renewables
- Consumer participation in Energy Conservation

Concept of Smart Systems

Smart Generation

- Renewables & Micro Grid

Smart Transmission

- Integration of Renewable Energy sources
- Synchrophasor Technology: Placement of PMUs, PDCs, Analytics

Smart Distribution

- Advanced Metering Infrastructure (AMI)
- Outage Management System (OMS)
- Peak Load Management (PLM)
- Power Quality Management (PQM)
- Electric Vehicles (EVs)
- Energy Storage

Smart Grid Monitoring and Controls

- Utilizes the following transmission components
- Phasor Measurement Technique
- Wide Area Measurement (WAM)
- Flexible AC Transmission System (FACTS)
- Adoptive Islanding
- Self healing Grids
- Probabilistic and Dynamic Stability Assessment
- Distributed and autonomous Control

PMU Deployment and Control Information

- Time synchronized sub-second data
- Information of Dynamic behavior
- Directly provides the phase angles
- (State Estimation to State Measurement)
- Improves post disturbance assessment
- High data rates and low latency due to computation

RELIABLE AND INTELLIGENT GRID INFRASTRUCTURE

- More intelligent network –incl. DER and Microgrids Major effort at all levels/ must assign value/ prioritize
- •Expanded transmission (who decides, who pays?)
- •Regulatory issues
- –Fragmented regulation impedes penetration of technology that operates across boundaries
- –Regional planning
- –Increase fuel security for natural gas generation

NATIONAL SECURITY AND ENERGY SECURITY

- Renewables and distributed generation
- Electrify the Vehicle Fleet; Use of Alternative Fuels
- Is there a grid issue?
- Cyber-security and interoperability must be built in
- Fast reconfiguration and self-healing options
- Threat coordination

Evolving Grid Framework in New Regulations

- SMARTER-Enhance customer experience
- STRONGER-Improve resiliency and security
- GREENER-Increase renewable integration

GRID OPERATION: Challenges
A TIGHT ROPE WALK

- Power Oscillations Damping Control
- HVDC Control for an Operating Conditions
- Limitations of Existing Controllers
- Linkage of Design Considerations & Operating Concept
- Operational Constraints of HVDC Converters in Renewable Energy Era- Analysis

THANKS