Part 2
SMART GRID SYSTEMS

PE/PE/HT/324C

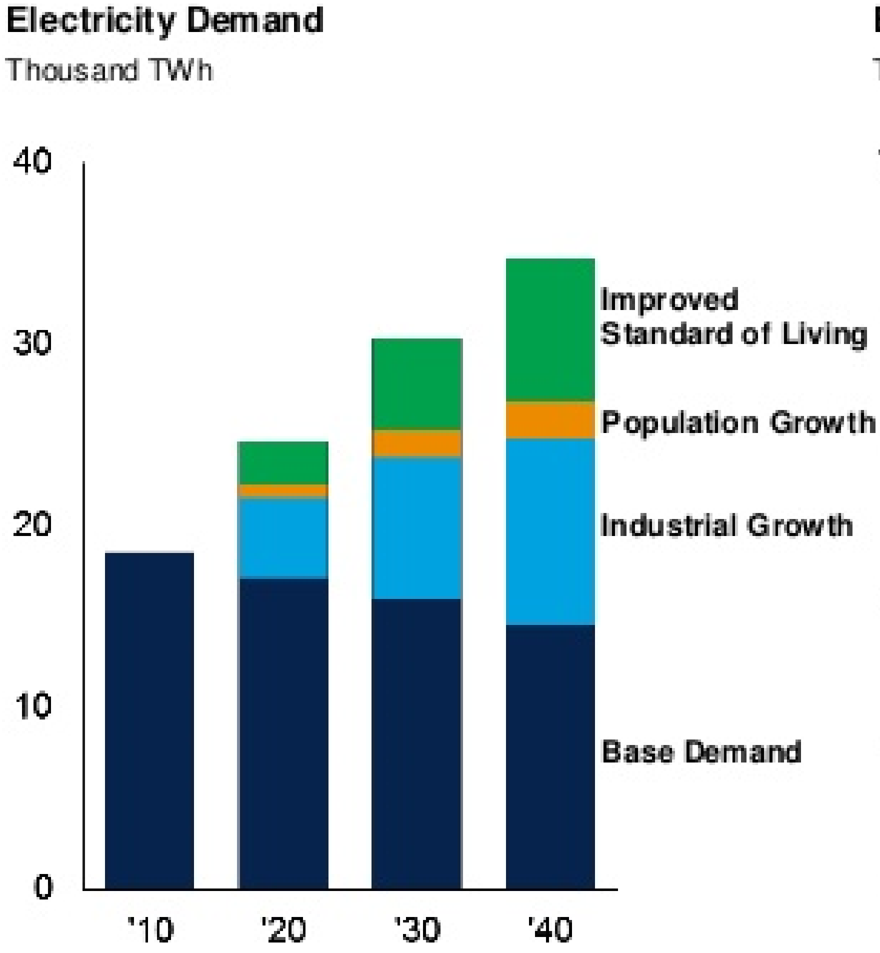
Professional Elective Course

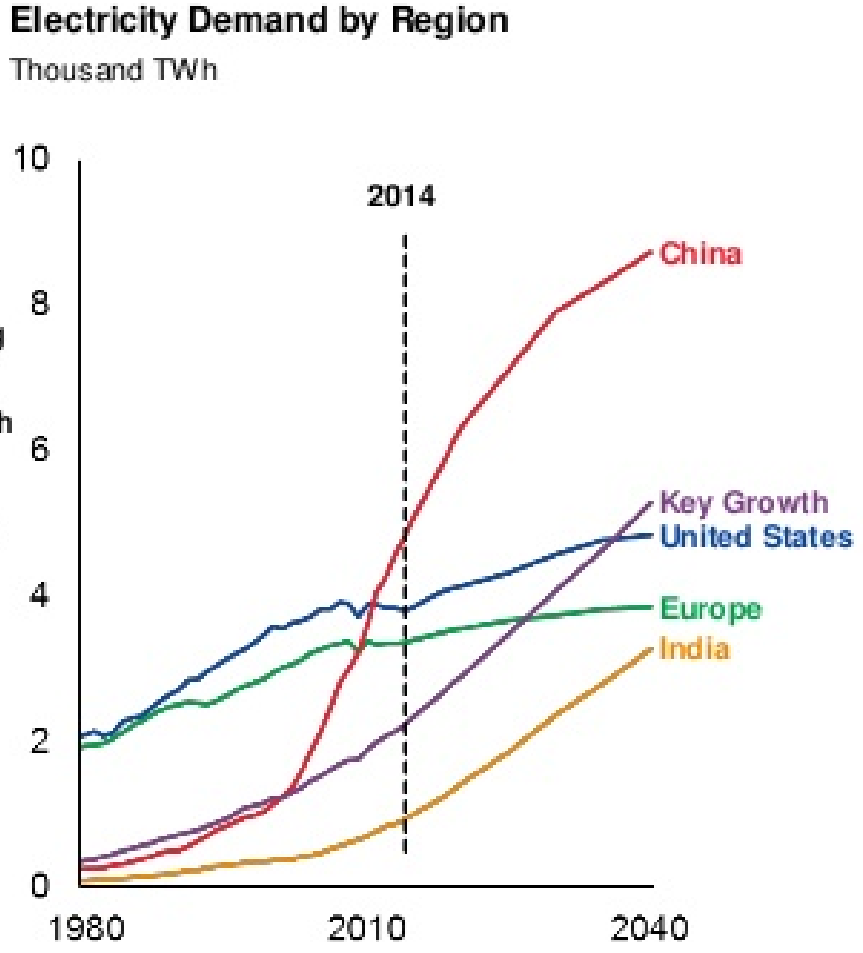
ILOs

- Why smart grid
  - Meeting increasing demand
  - Reducing high Aggregate Technical & Commercial (AT & C) Losses
  - Better utilization of ageing assets
  - Transparent and efficient billing and collections
  - Ready for energy mix
  - Deliver sustainable energy
  - Quick and efficient fault diagnosis
  - Increase operational efficiency
  - Empower consumers
  - Improve reliability
- Features of Smart Grid
- Challenges for Smart Grid

Why smart grid?

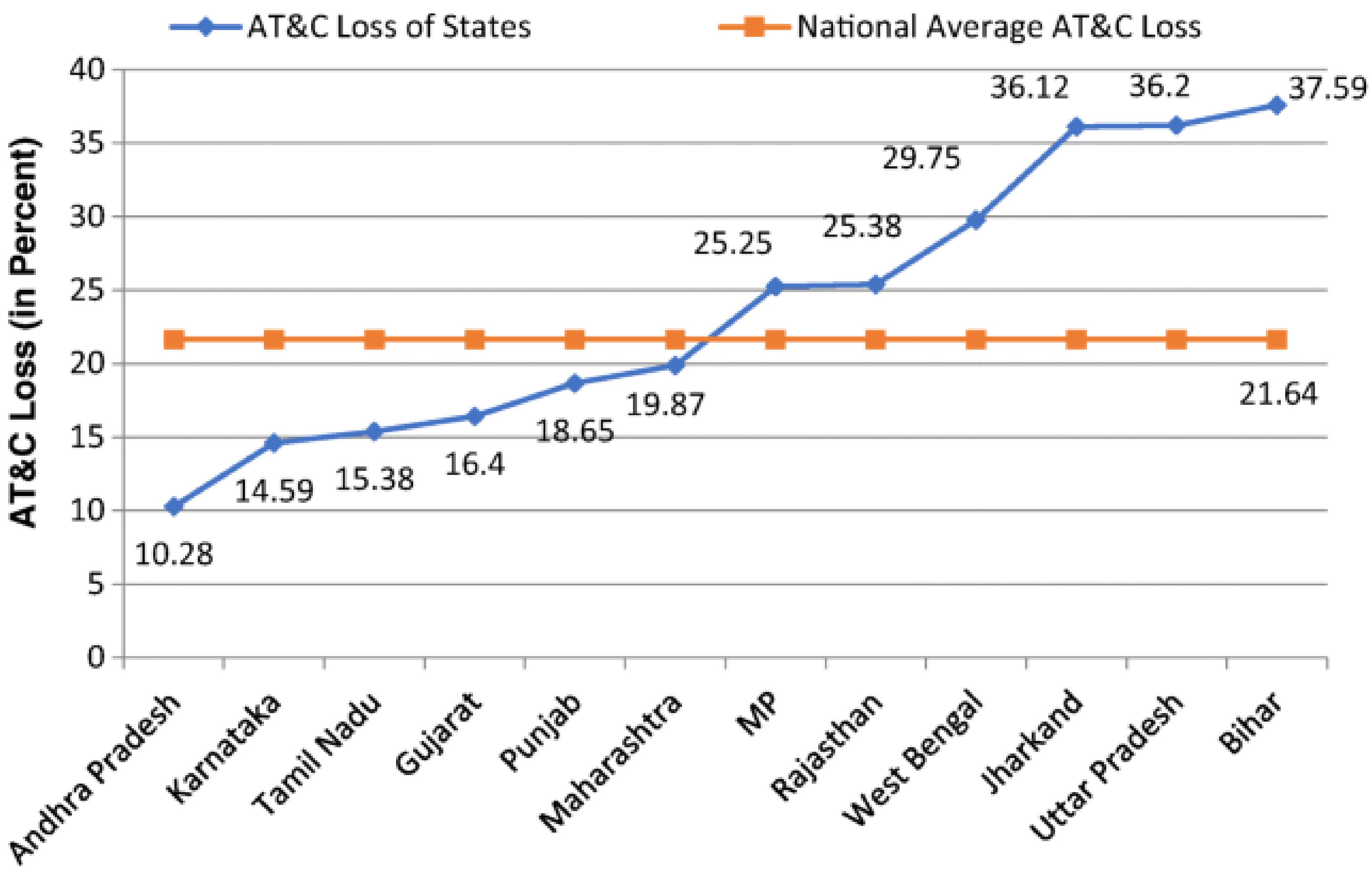
- Meeting increasing demand
  - Grid to carry more power: Need for, Reliability and greater Security





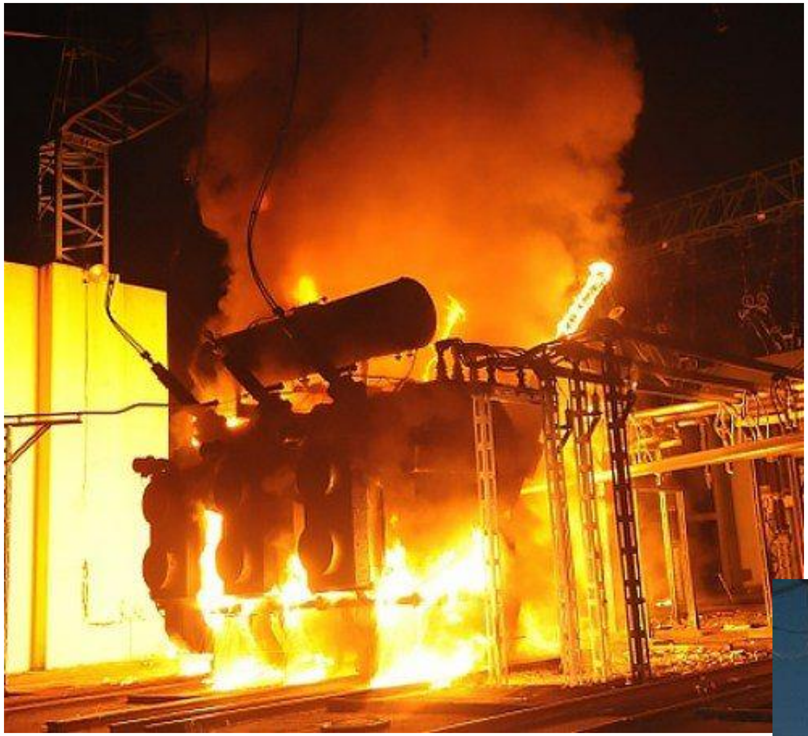
Why smart grid?

- Reducing high Aggregate Technical & Commercial (AT&C) Losses



Why smart grid?

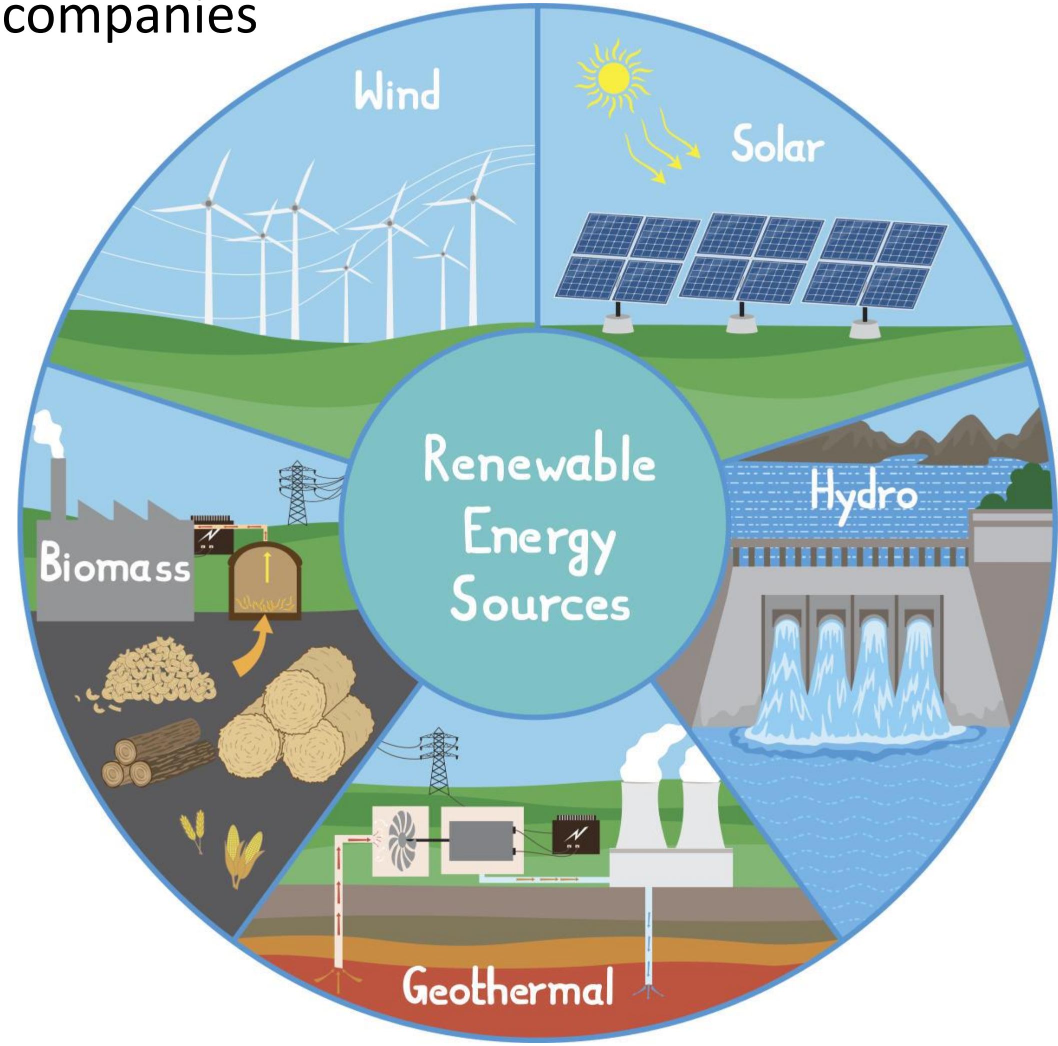
- Better utilization of ageing assets
  - Transformers, Feeders, Circuit breaker, isolator etc.,



Why smart grid?

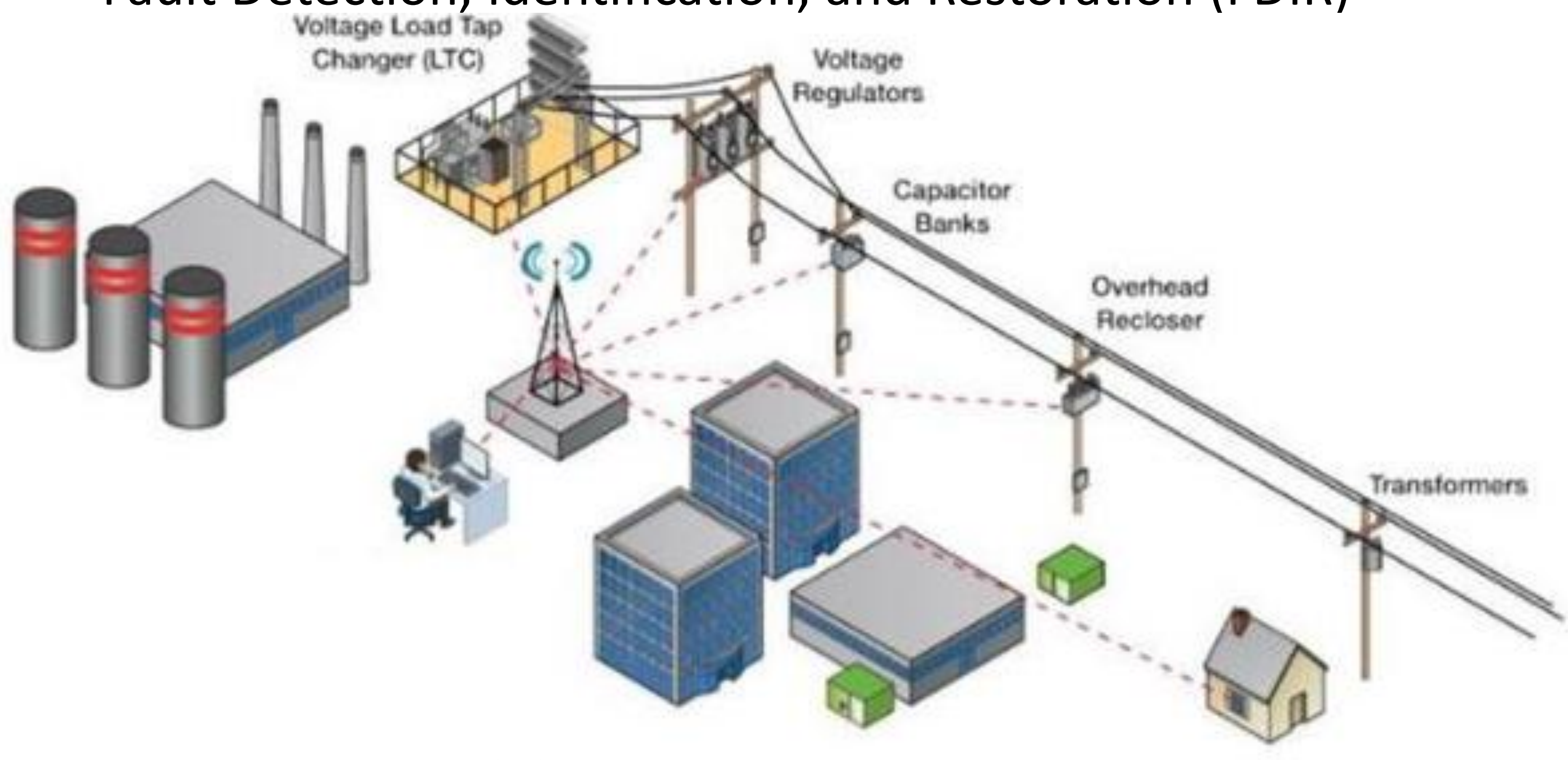
- Transparent and efficient billing and collections
  - Profitability of distribution companies

- Ready for energy mix
  - Need for Renewable Energy (Hydro Power, PV, Solar Thermal Energy, Wind, Biomass, Biogas, etc.) to reduce carbon footprint



Why smart grid?

- Deliver sustainable energy
  - Voltage & VAR control
  - Resource planning
  - Analysis and monitoring
  - Forecasting tools
  - Fault Detection, Identification, and Restoration (FDIR)



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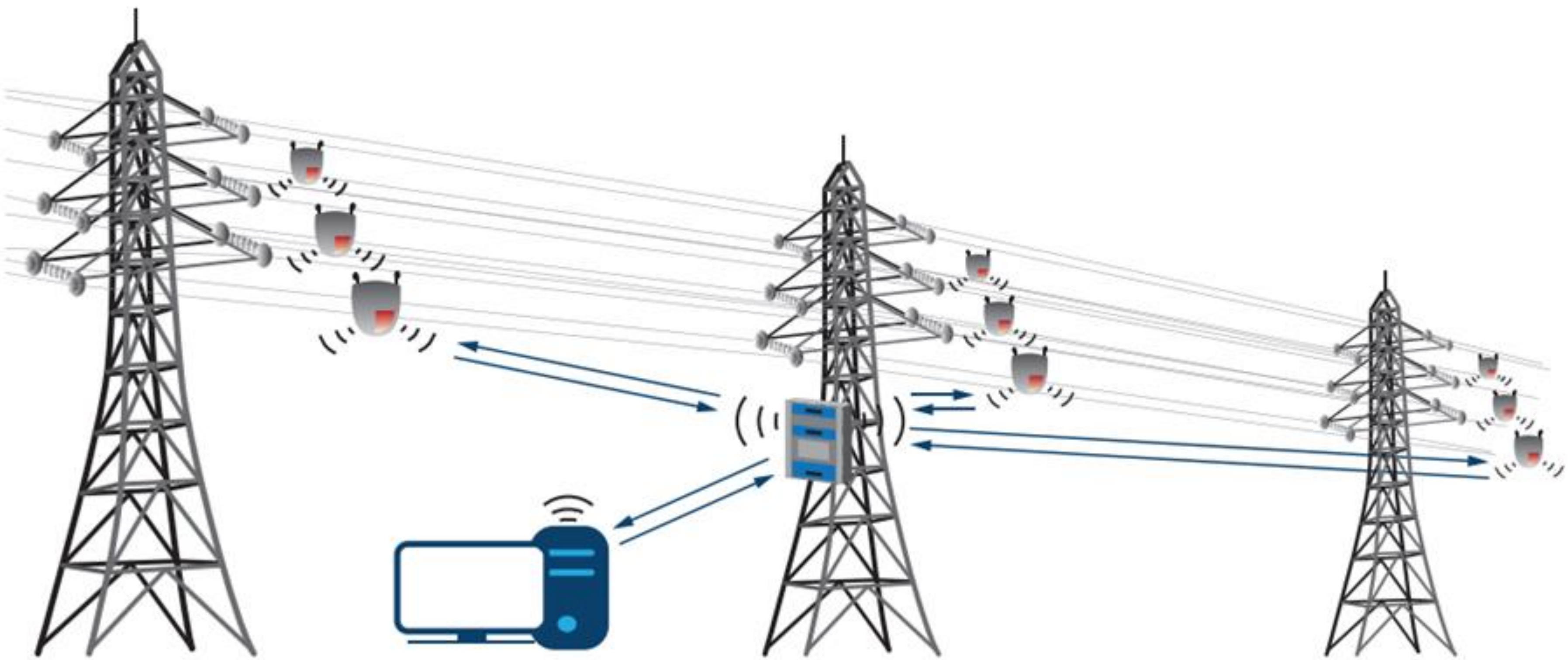
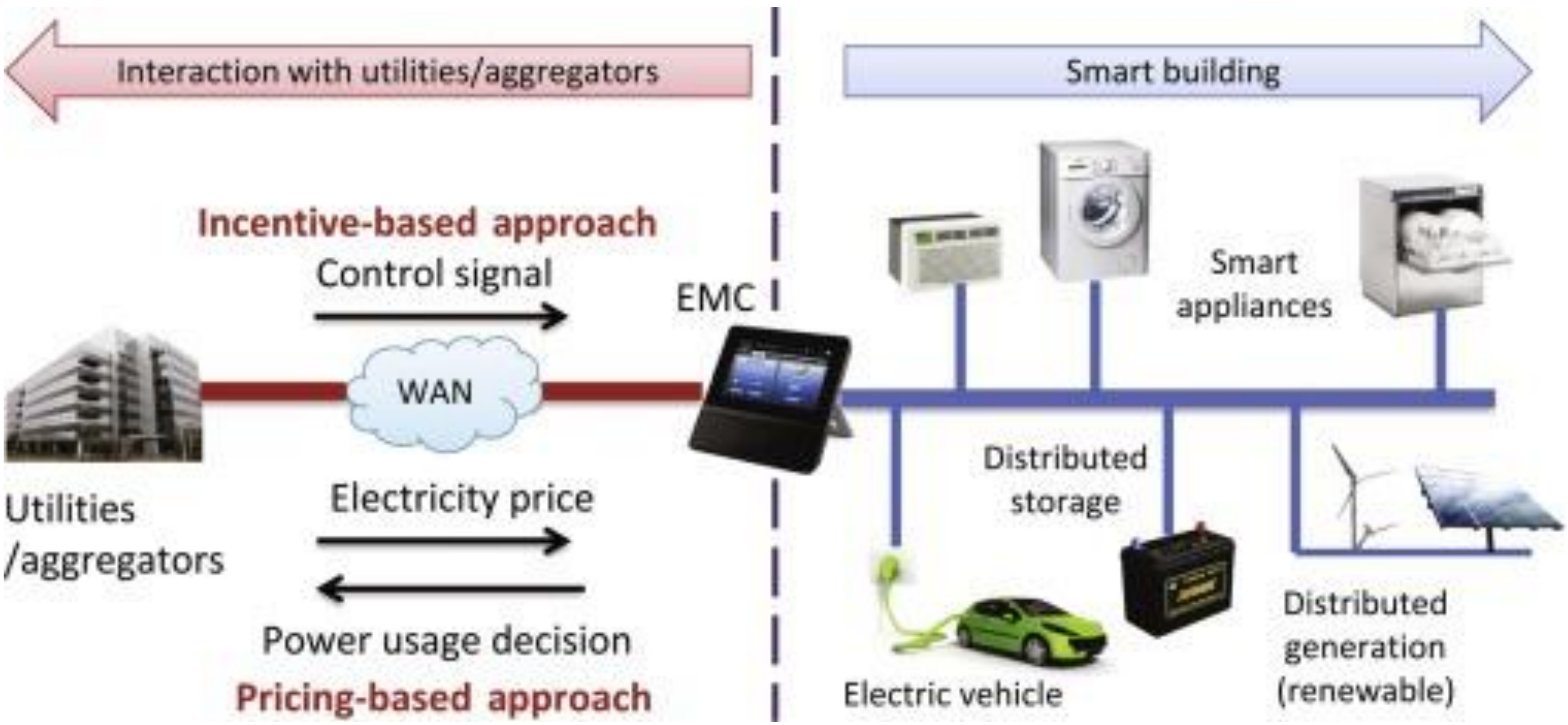


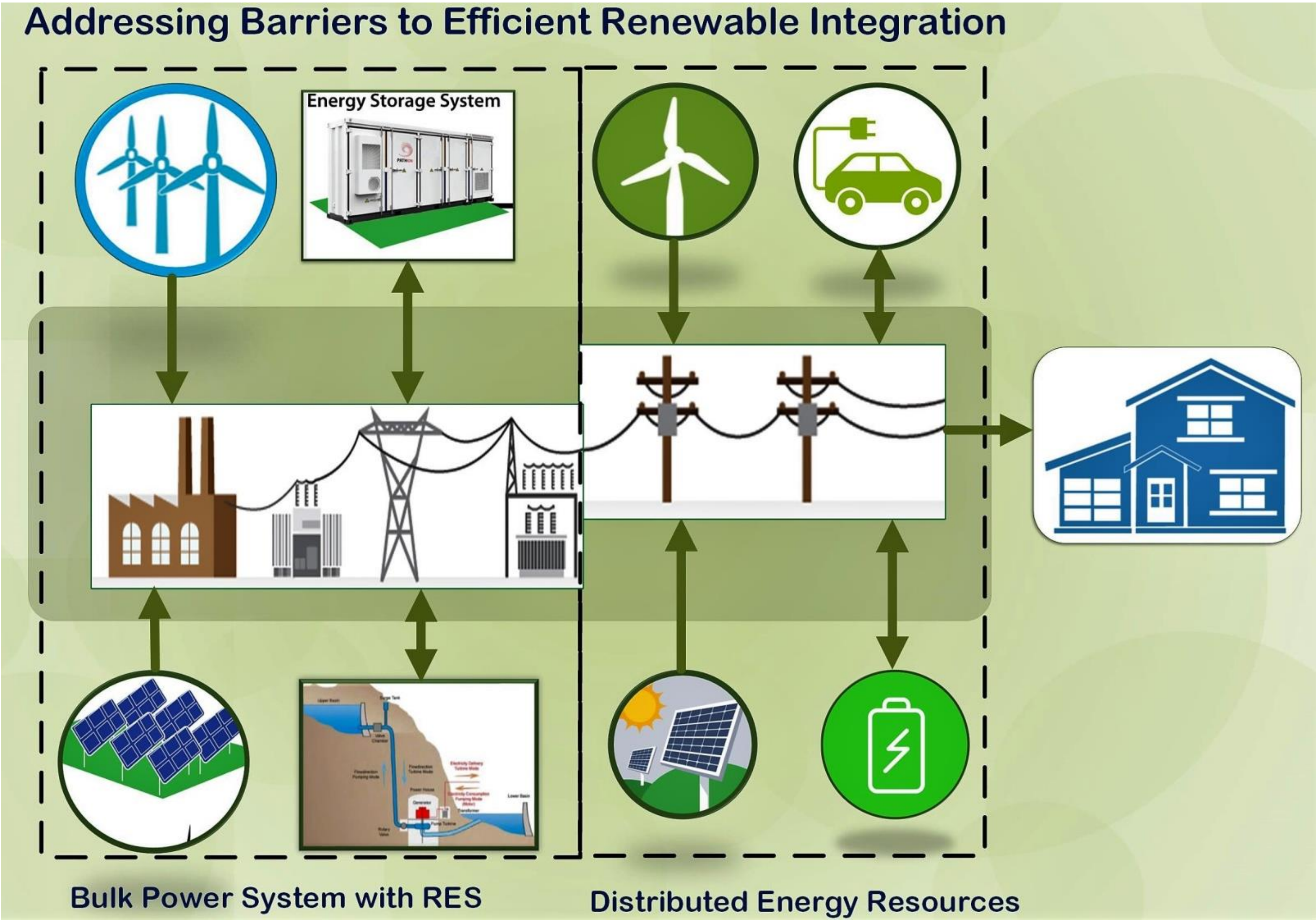
Why smart grid?

- Increased operational efficiency
  - EMC – Energy Management Controller



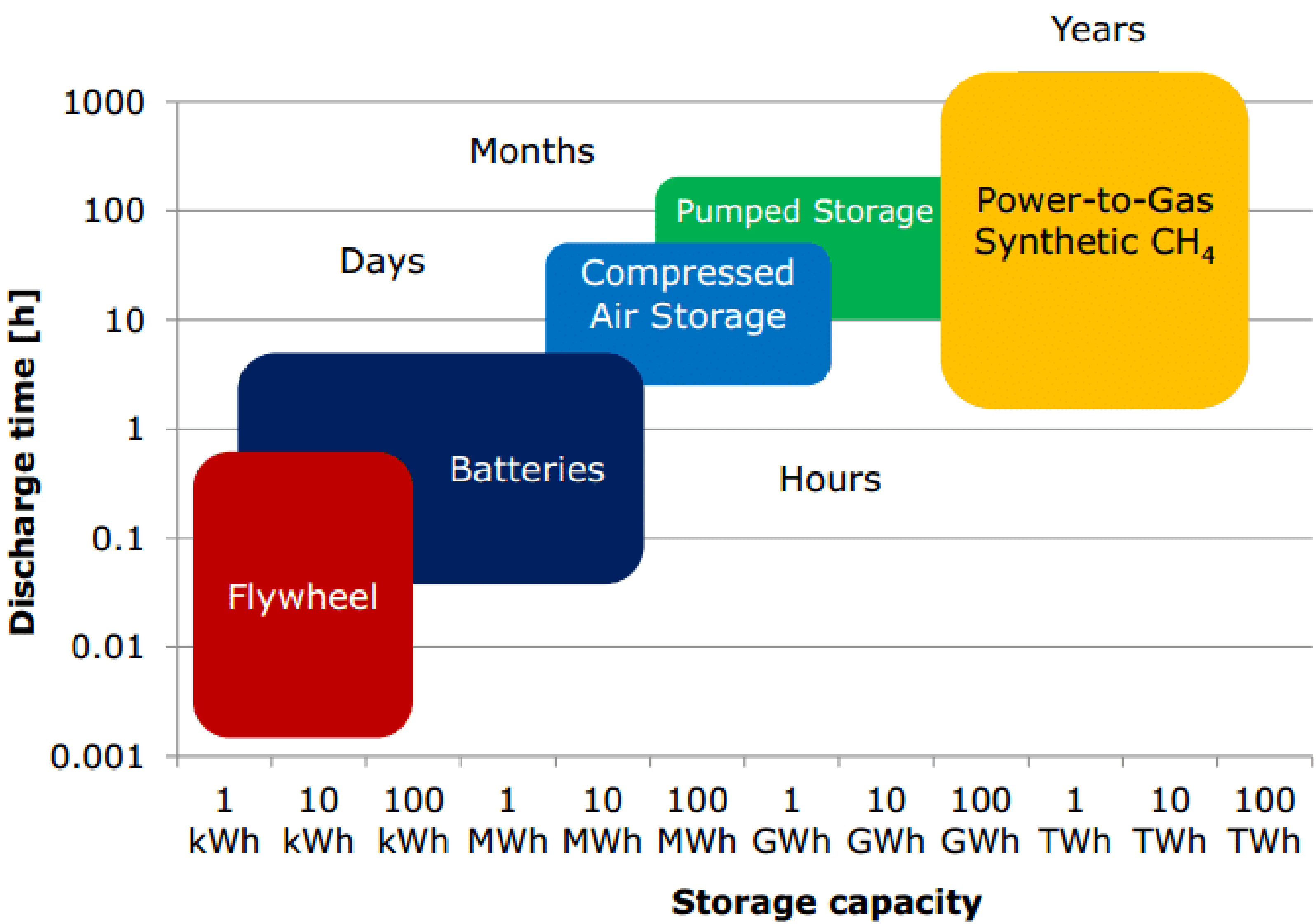
Why smart grid?

- Distributed energy resources integration



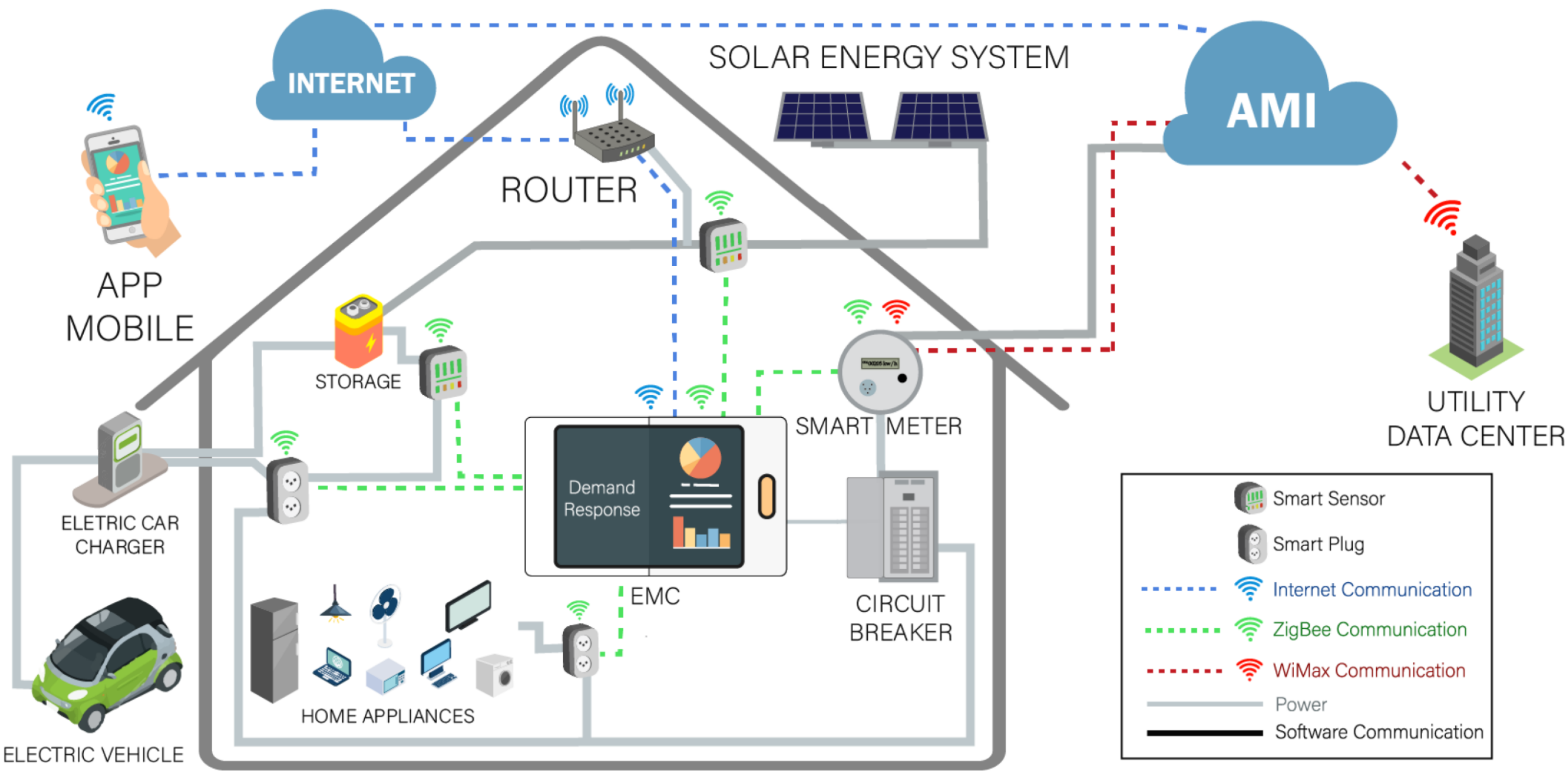
Why smart grid?

- Energy storage



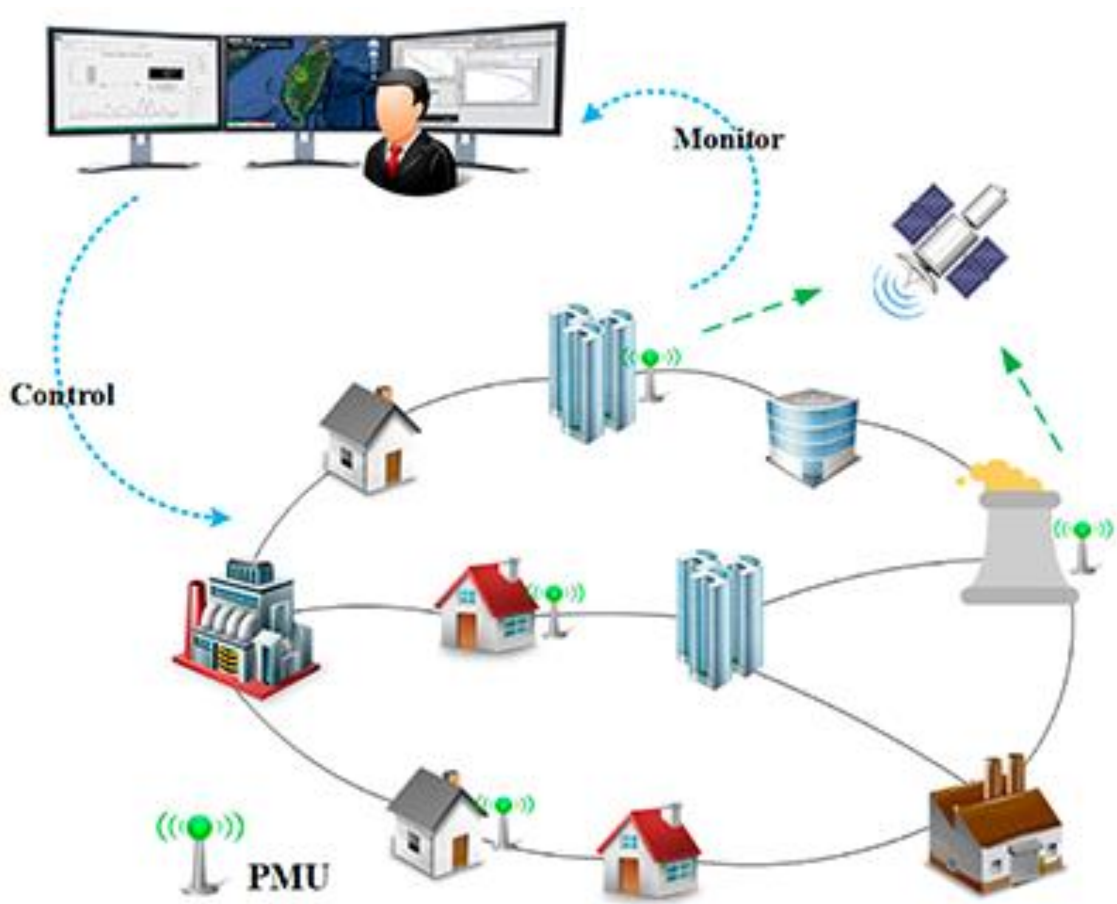
Why smart grid?

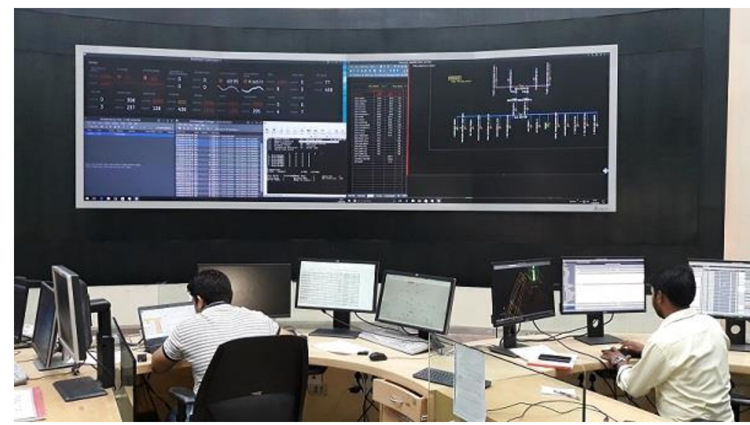
- Empower consumers
  - Consumer education and awareness
  - Residential consumer energy management



Why smart grid?

- Improve reliability
  - System wide monitoring, measurement and control





Why smart grid?

- Advanced metering infrastructure (AMI) – Smart meter

Features of Smart grid

Increased grid visibility and self-healing grids

Clean Energy Development

- Reduction in CO_2 Emission
- Improved Environmental Conditions

Motivates and Includes the Consumer

Improved billing mechanism

- Enabling Energy Audit
- Reduction in Cost Billing
- Options such as ToU tariff, net metering

Features of Smart grid

- Efficient load management (LM) techniques
- Integration of Renewable Energy
- Optimizes Assets and Operates Efficiently
- Safe, Reliable, Efficient, and Quality power supply
- Improved National Security
- Improved Economic Growth
- Better asset management

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Features of Smart grid

Self-Healing smart grid vision

- Respond to threats, material failures, and other destabilizing influences by preventing or containing the spread of disturbances
- Timely recognition of impending problems
- Redeployment of resources to minimize adverse impacts
- A fast and coordinated response to avoid disturbances
- Minimization of loss of service under any circumstances
- Minimization of time to reconfigure and restore service

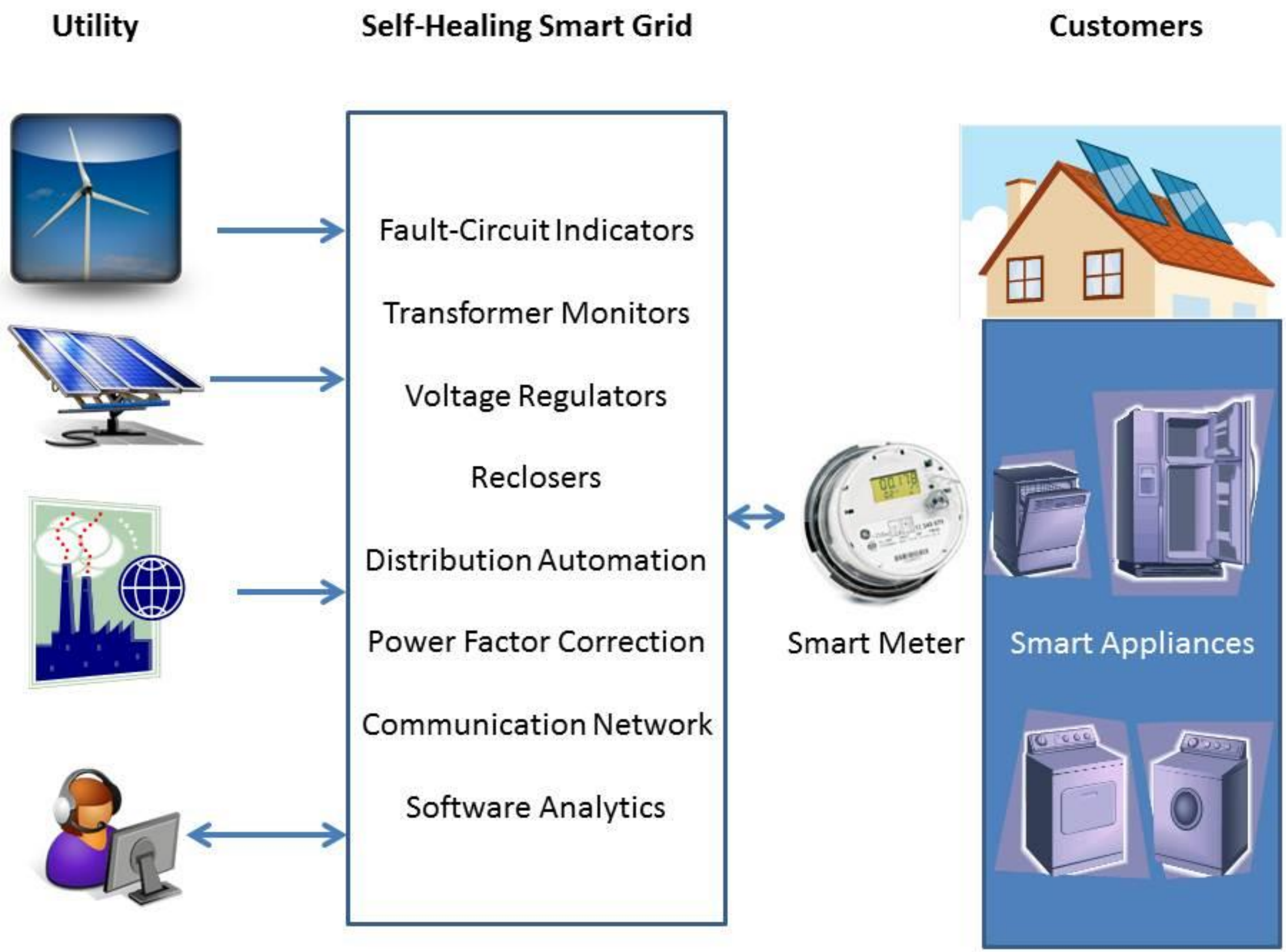
Features of Smart grid

Self-Healing smart grid goals

- **Reliable systems** - Systems that are generally dependable w.r.t their ability of service delivery
- **Fault-tolerant systems –** When fault occurs, the system is not affected
- **Resilient systems** – Systems that could be reconfigured to cope with disturbances

Features of Smart grid

- **Self-Healing smart grid components**



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Features of Smart grid

- **Reduction in CO_2 Emission**

Smart Power

Utilities can optimize voltage and load, to eliminate overkill, prevent blackouts and avoid building new capacity

- Stabilize and optimize voltage
- Reduce peak demand
- Reduce transmission losses

Decentralized Power

Power generation is localized, so transmission and distribution losses are lower

- Use software to aggregate distributed energy sources
- Reduce distribution losses
- Create micro-grids

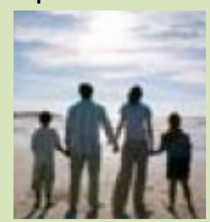
Smart renewable

Energy storage and real-time data make RES more reliable and reduce the need for fossil back-up power

- Continuously adjust power sources to solve the variability problem of RES
- Store RE energy generated

Smart end-users

Industrial, commercial and residential users can reduce energy use and help utilities shift power loads from peak to non-peak times

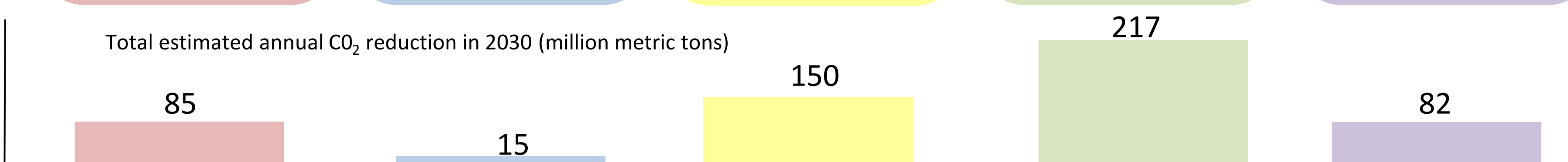


- Automatically control and manage energy usage
- Allow utilities to remotely control HVAC

Electric Vehicles

Vehicle batteries Provide decentralized energy storage and help utilities even out power loads

- Accommodate plug-in hybrid and all-electric vehicles
- Charge vehicles in non-peak hours and sell energy back to the grid in peak hours



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Features of Smart grid

- **Motivates and Includes the Consumer**

  - If no participation from customer, then the Smart Grid is invisible
  - Manage their power consumption to avoid power outage
  - Buy/sell energy from/to the grid
  - Get incentives from utility by shifting their energy use to low peak demand

Features of Smart grid

Increased grid visibility and self-healing grids

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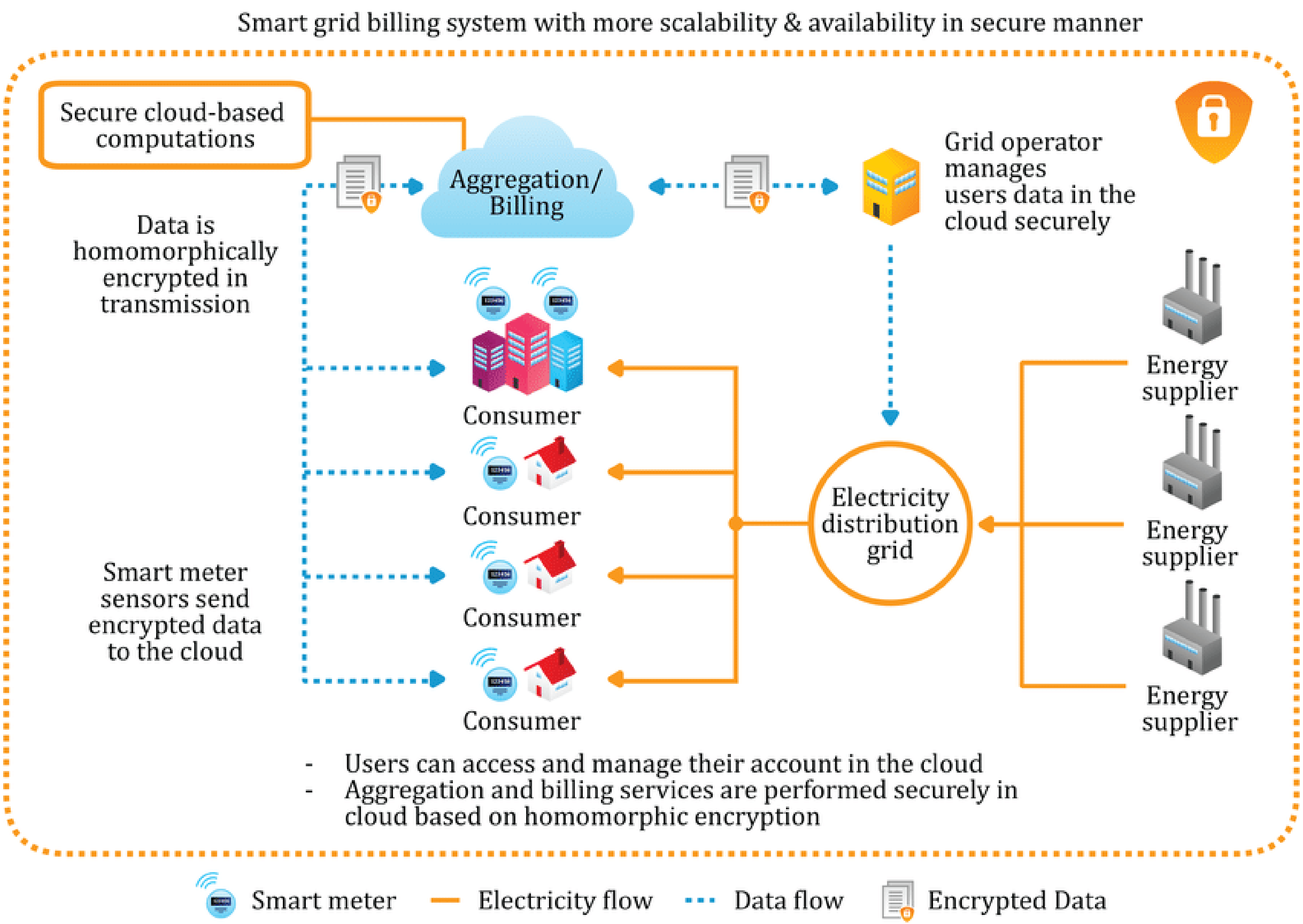
- **Improved billing mechanism**



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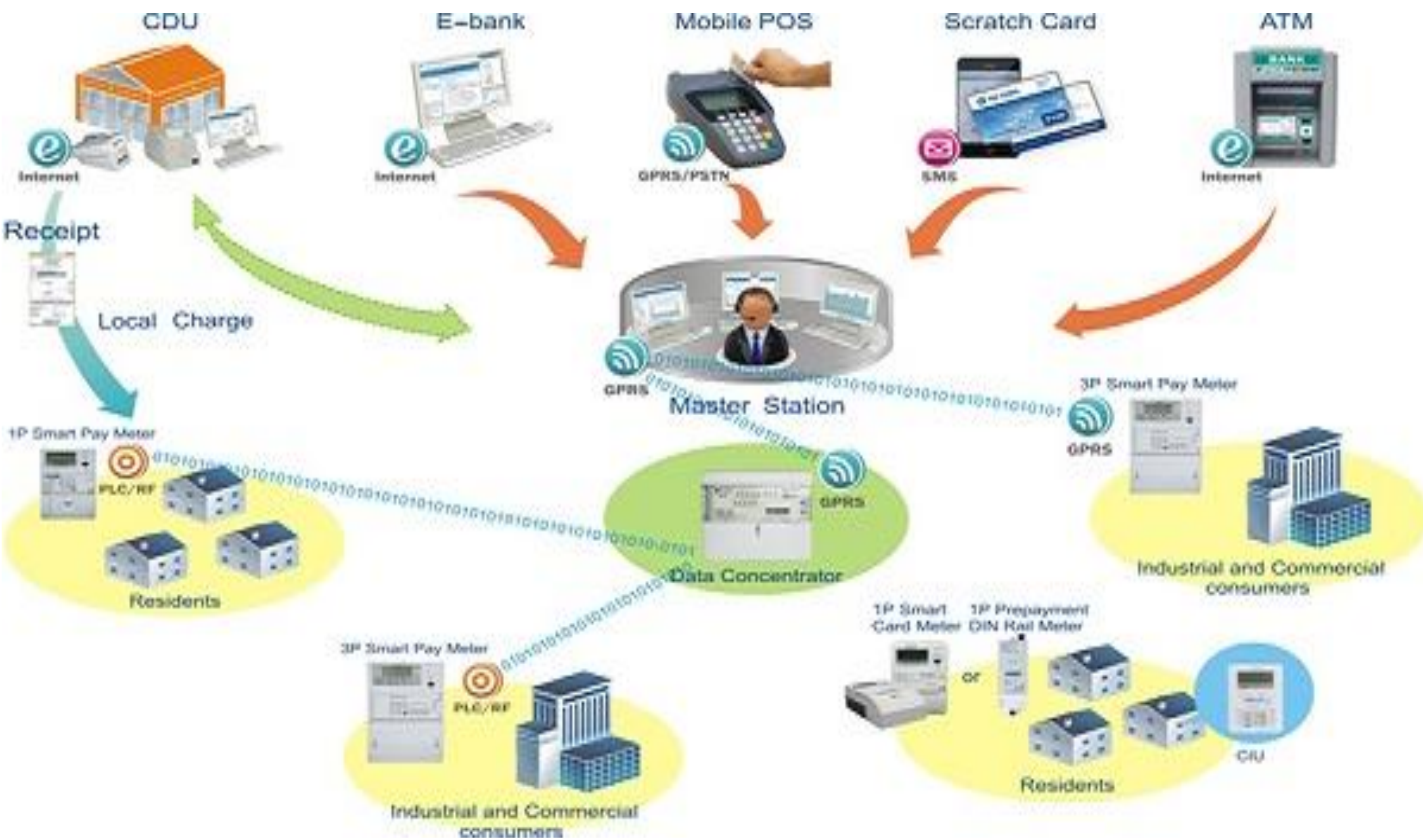
- **Improved billing mechanism**



Features of Smart grid

Efficient load management (LM) techniques

- Incentive based direct load control
- Dynamic pricing based energy consumption scheduling

Integration of Renewable Energy

Optimizes Assets and Operates Efficiently

Safe, Reliable, Efficient, and Quality power supply

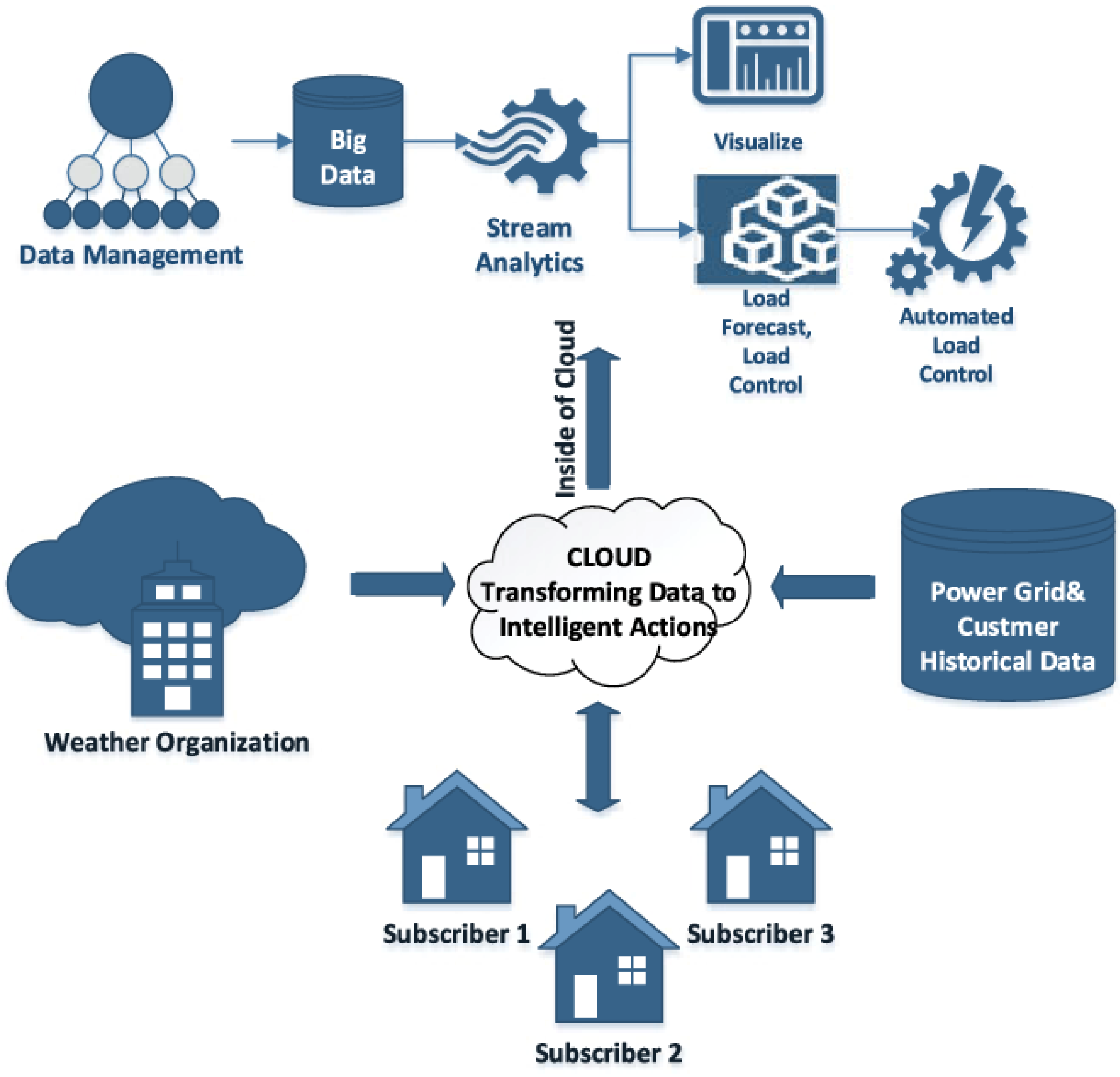
Improved National Security

Improved Economic Growth

Better asset management

Features of Smart grid

- **Efficient LM techniques –** Incentive-based direct load control (DLC)



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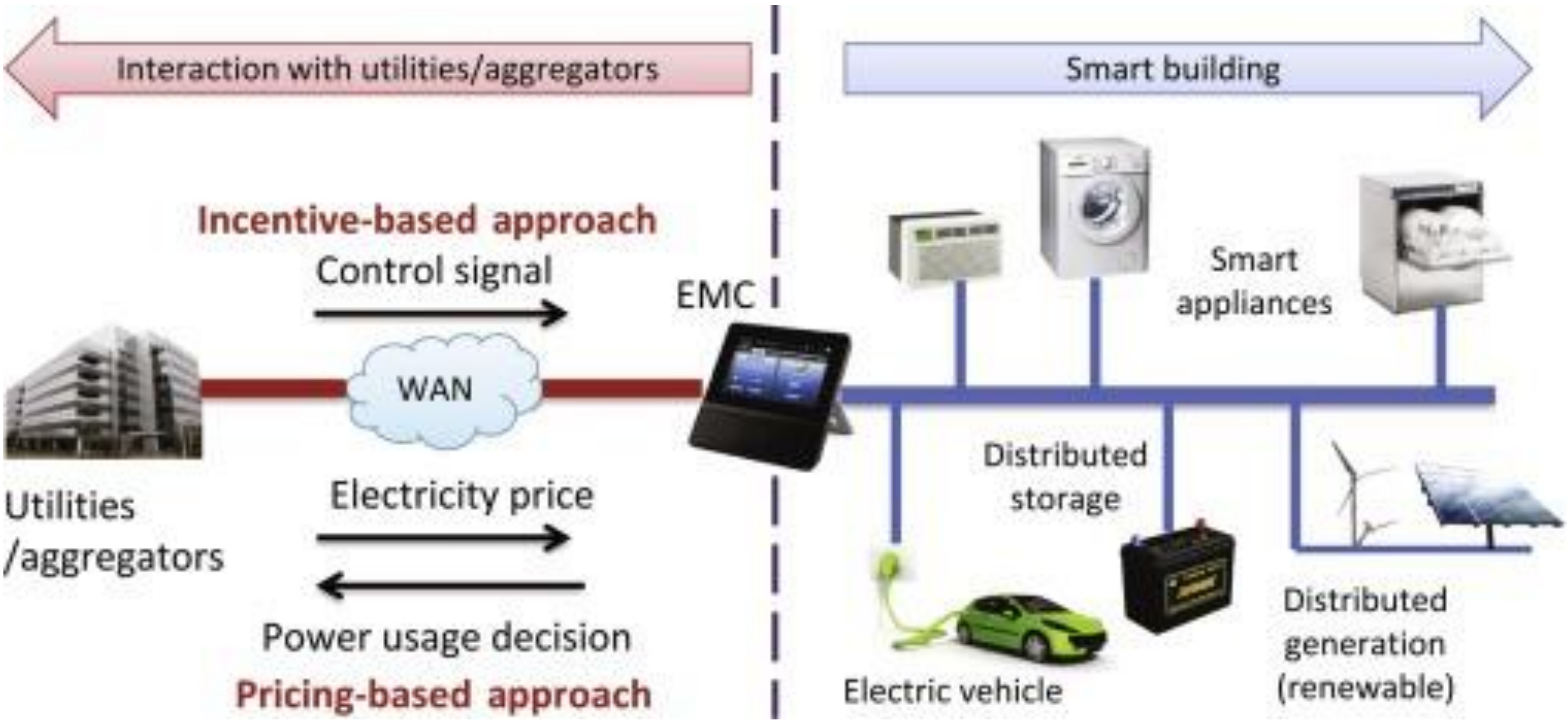
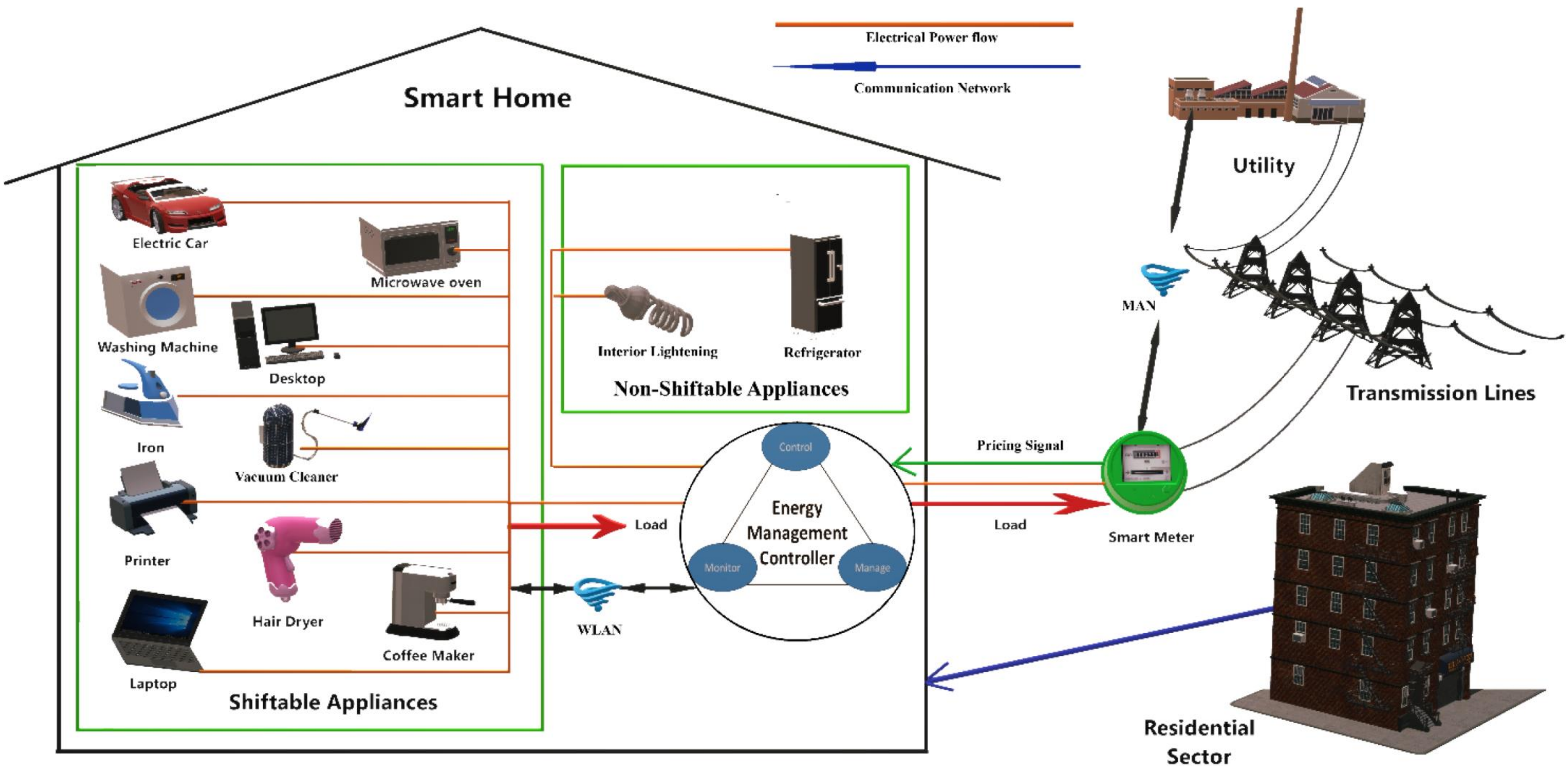


Features of Smart grid

- **Efficient LM techniques –** Dynamic pricing-based energy consumption scheduling (ECS)



Features of Smart grid

- **Efficient LM techniques**

Dynamic pricing-based energy consumption scheduling (ECS)	Incentive-based direct load control (DLC)
Switch is in user's hands	Switch is in utility's hands
Reduced cost of energy during off-peak hours	Incentive payments for load shedding, and inconvenience cost payments
Load control by load shifting, that is, more flexible for users	Load control by load shedding, that is, more flexible for utilities
Requires active participation and awareness of consumers	Does not require active participation and much awareness of consumers
Considered to be more effective for system stability during everyday life	Considered to be effective during event days
Relatively less potential of peak load reduction because of lighter loads	It has more potential of peak load reduction as it is usually applied on heavy loads
More cyber security concerns during real-time energy consumption monitoring	Less vulnerable with respect to data theft
Needs large no. of devices at residential level	Needs relatively less no. of devices to control heavy loads

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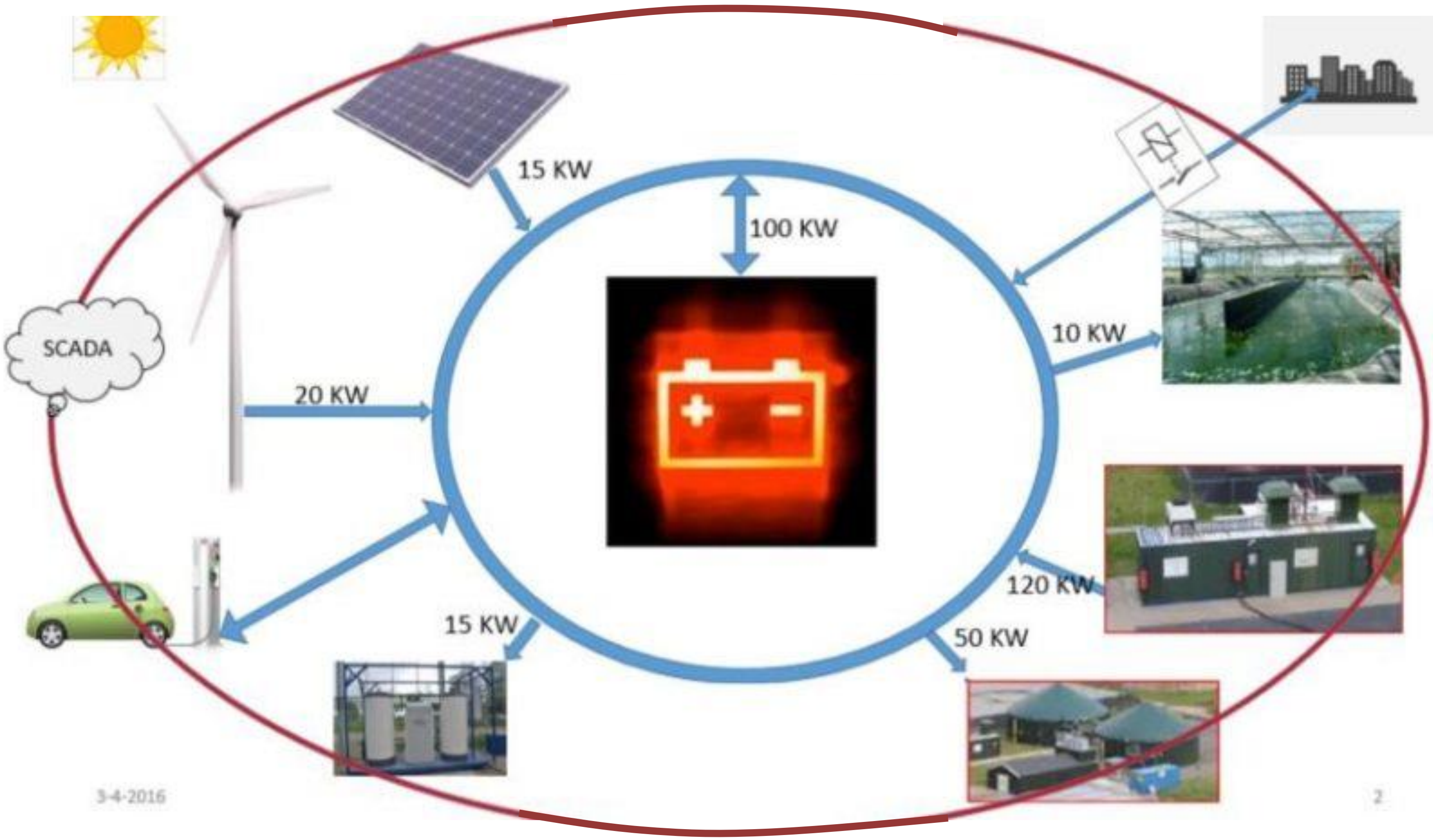
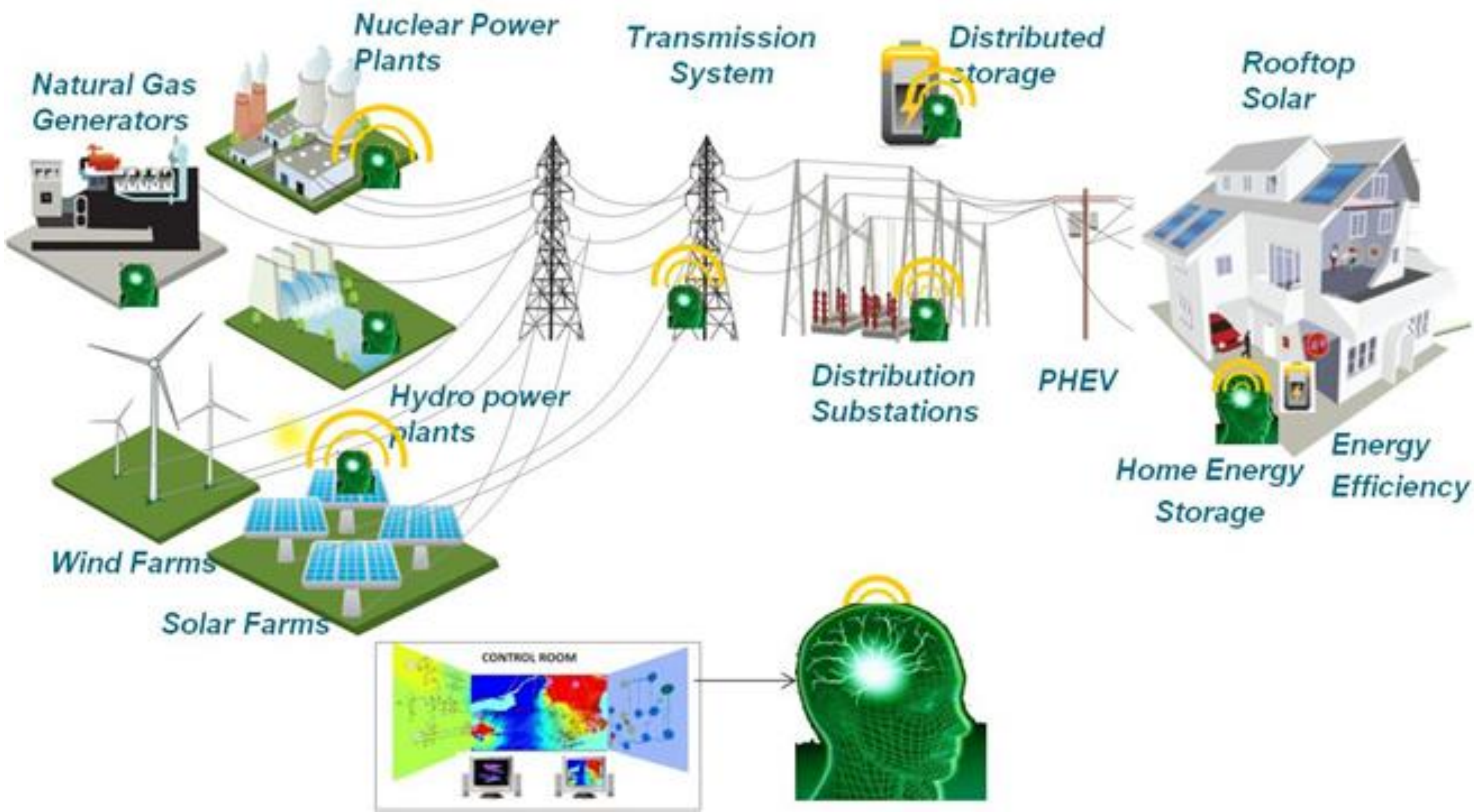
- **Integration of renewable energy**
  - Smart grid technology is enabling the effective management and distribution of renewable energy sources



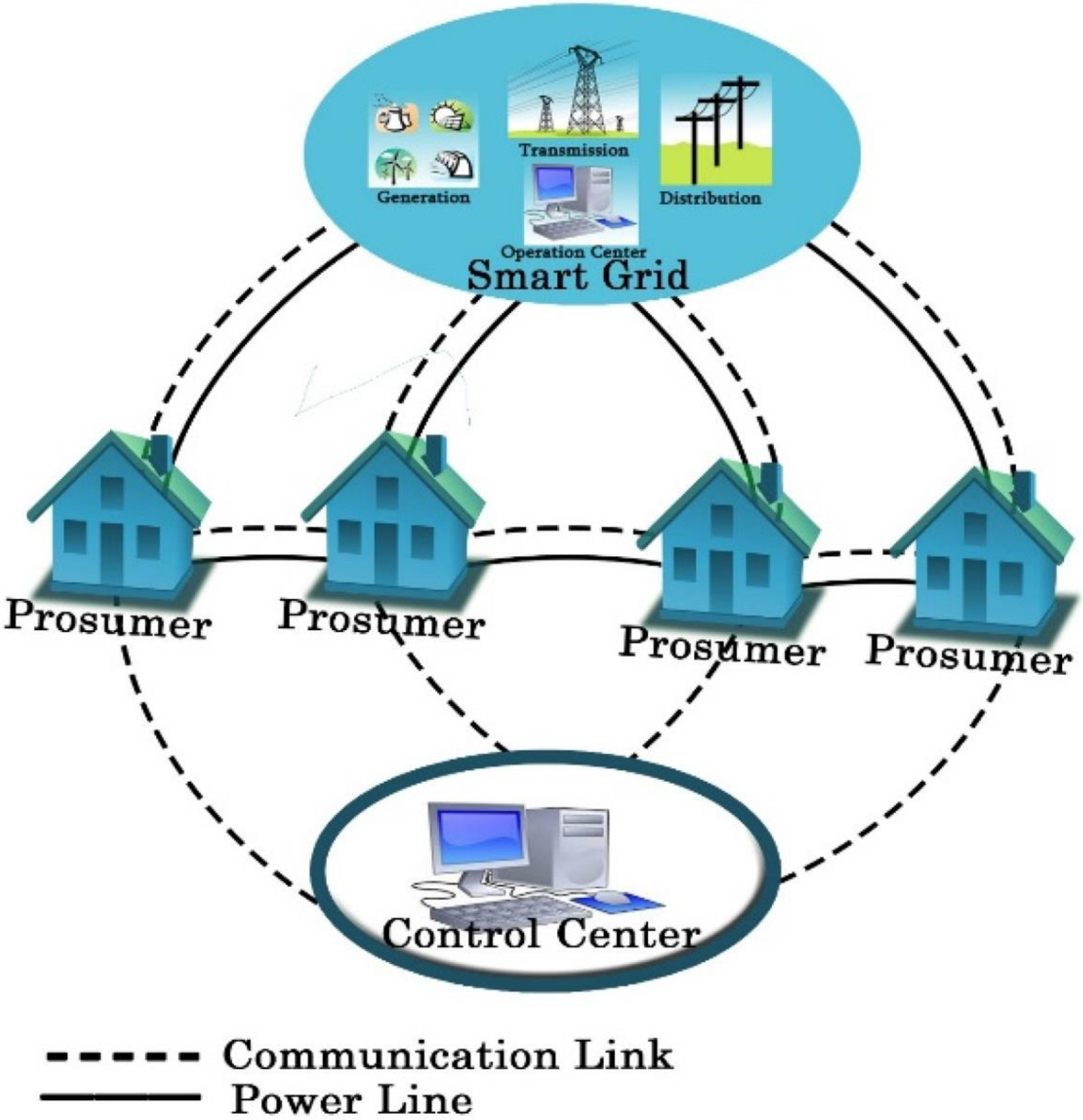
Features of Smart grid

- **Integration of renewable energy**
  - SG allows movement and measurement of energy in both directions using control systems and net metering



Features of Smart grid

- **Integration of renewable energy**
  - This will help "prosumers" i.e. the consumers who both produce and consume electricity, to safely connect to the grid



Features of Smart grid

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Features of Smart grid

- **What is grid optimization?**
  - Grid optimization creates smart energy by reducing expenses by:
    - Improving lifetime of assets
    - Balancing assets to get the most efficiency from assets
    - Having more preventive maintenance to avoid outage

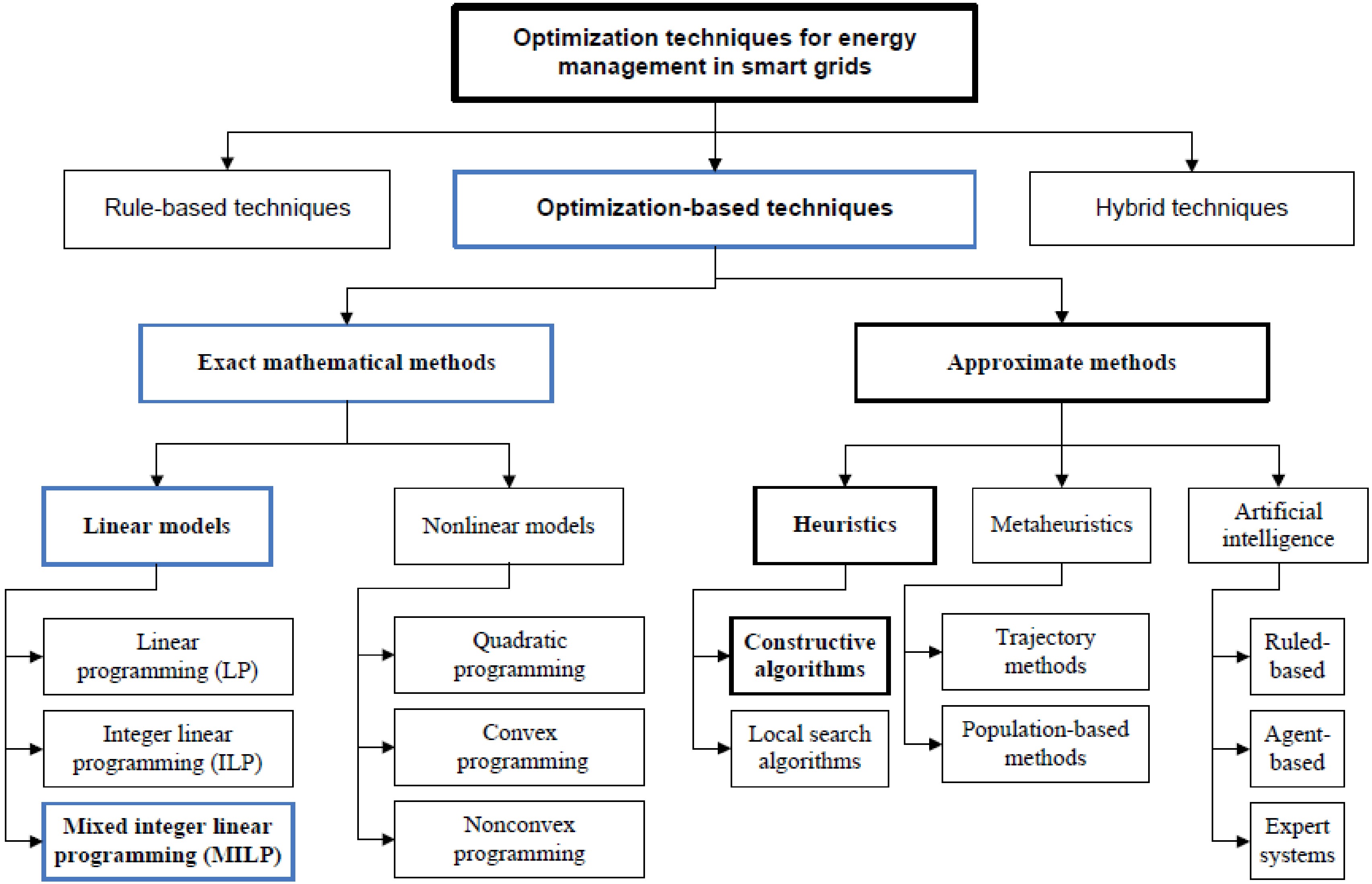
- **Components of grid optimization**
  - Transformer monitoring
  - Monitoring and automated control of LV assets
  - Usage of alarms in DMS
  - GIS integration
  - Basic outage management integration
  - Asset monitoring and management

Features of Smart grid

- **Benefits of smart grid optimization**
  - Power transmission, distribution and utilization losses can be reduced
  - Reliability of grid is achieved
  - Emission of hazardous and pollutant gases are minimized
  - Minimizing the energy cost
  - Voltage fluctuation and uncertainty of power can be lessened and protection failure of devices can be foreshortened

Features of Smart grid

- **Optimization techniques**



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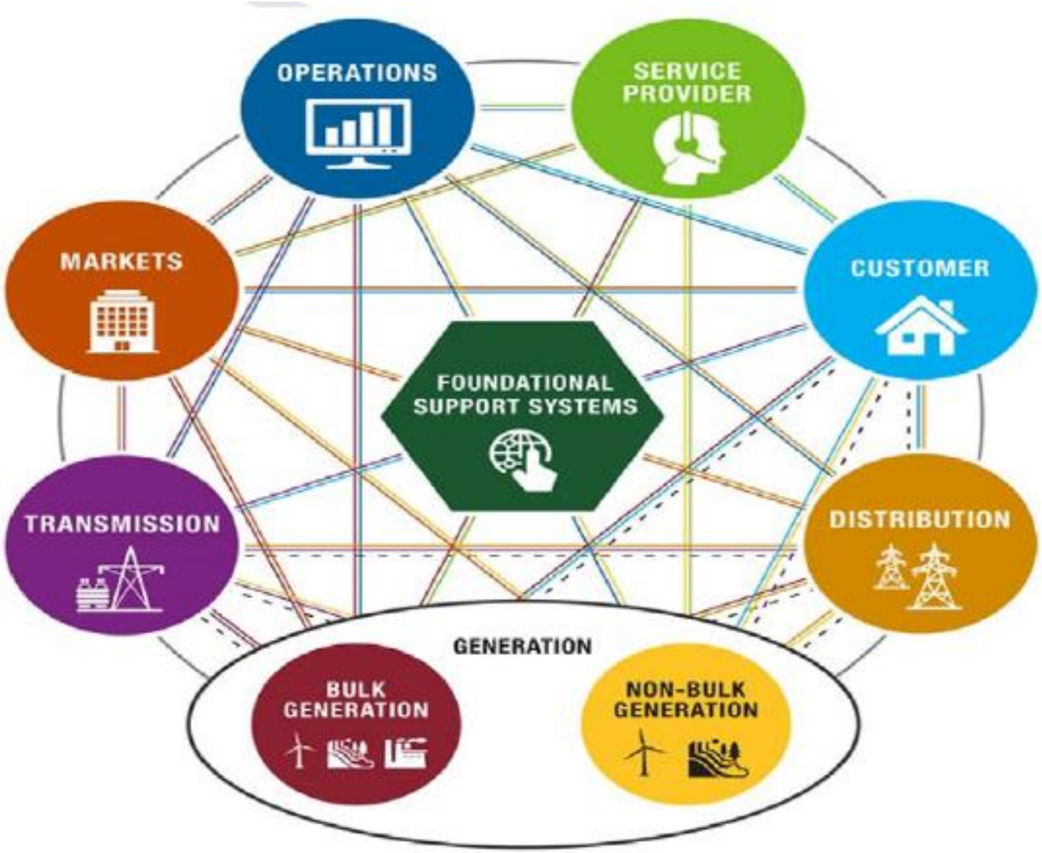
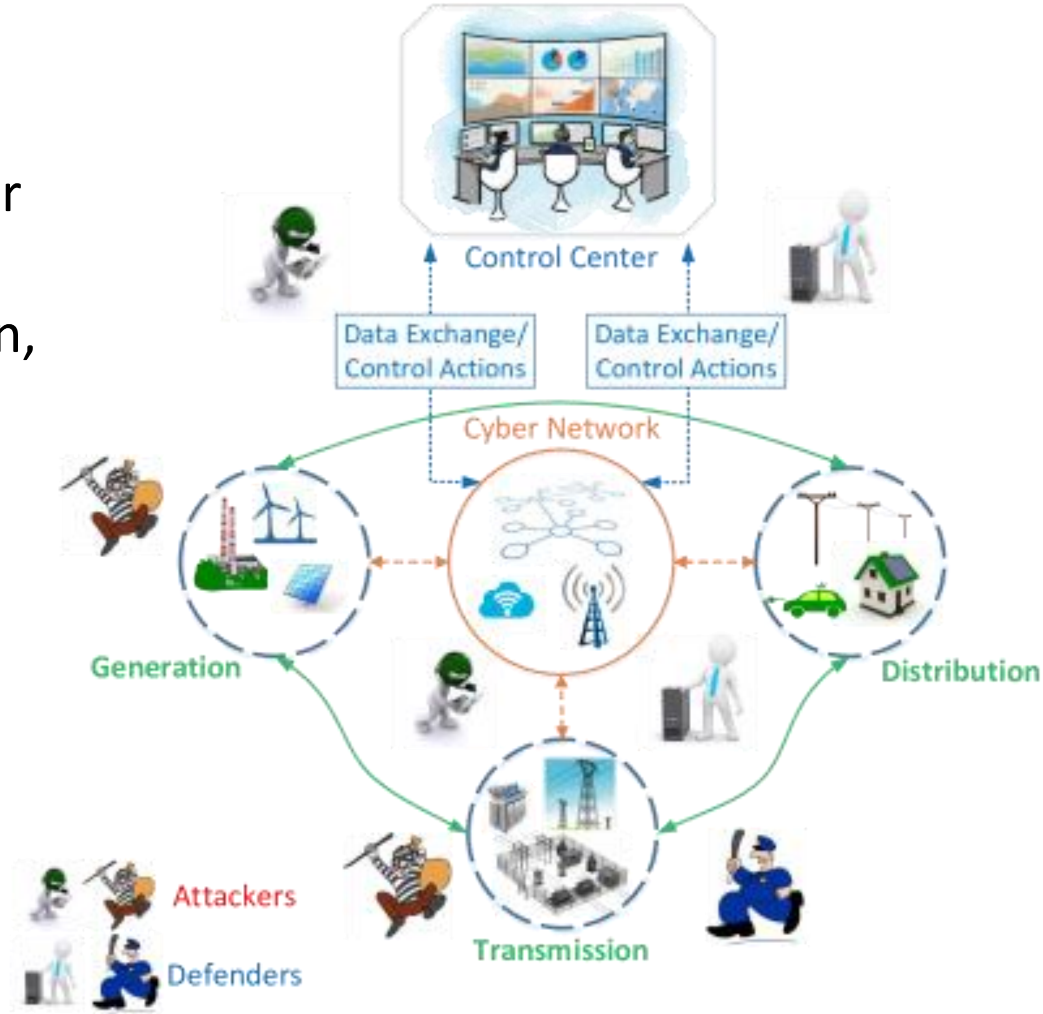
Features of Smart grid

- **Safe, reliable, efficient and Quality power supply**
  - Compared with conventional power systems, the Smart Grid is envisioned to fully integrate high-speed and two-way communication technologies into millions of power equipments to establish a dynamic and interactive infrastructure
  - However, such a heavy dependence on information networking inevitably surrenders the Smart Grid to potential vulnerabilities associated with communications and networking systems

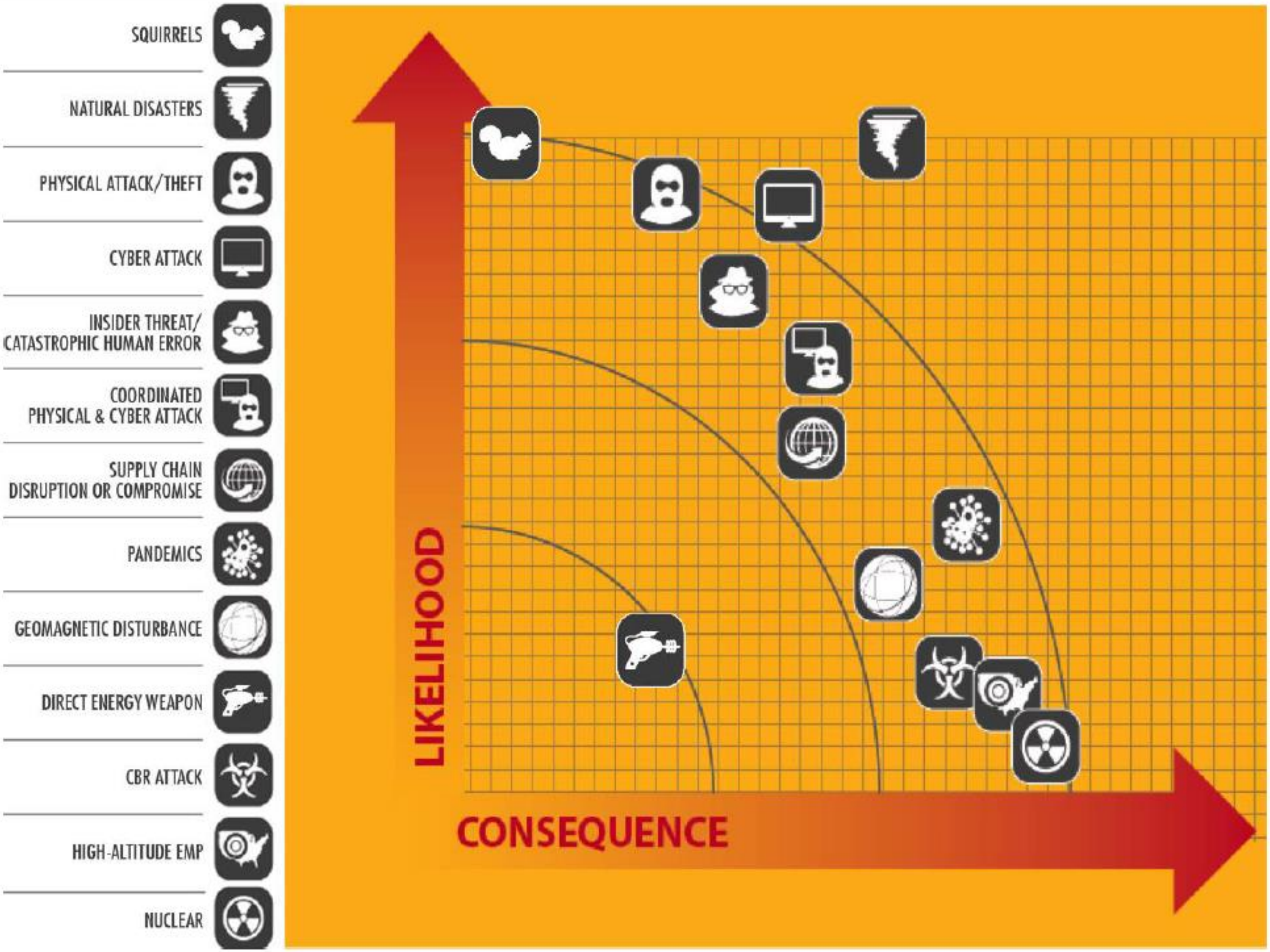


Security issues in smart grid

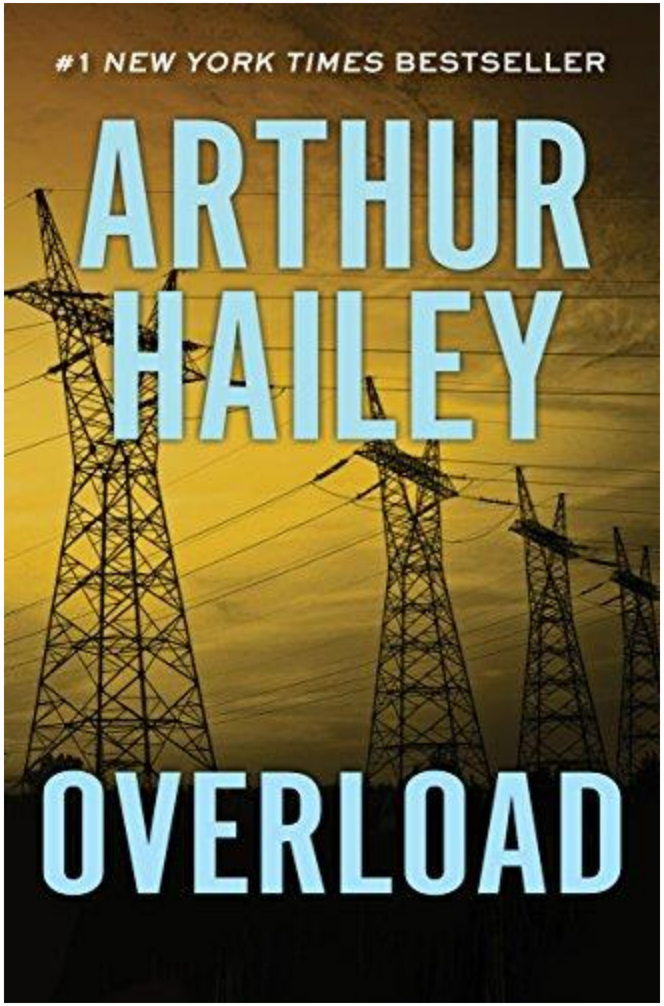
- Smart-grid is a *cyber-physical power system* in which a cyber layer that handles computations, communication, and data exchange, is tightly coupled with the physical system which handles the generation, transmission, and distribution of electric power

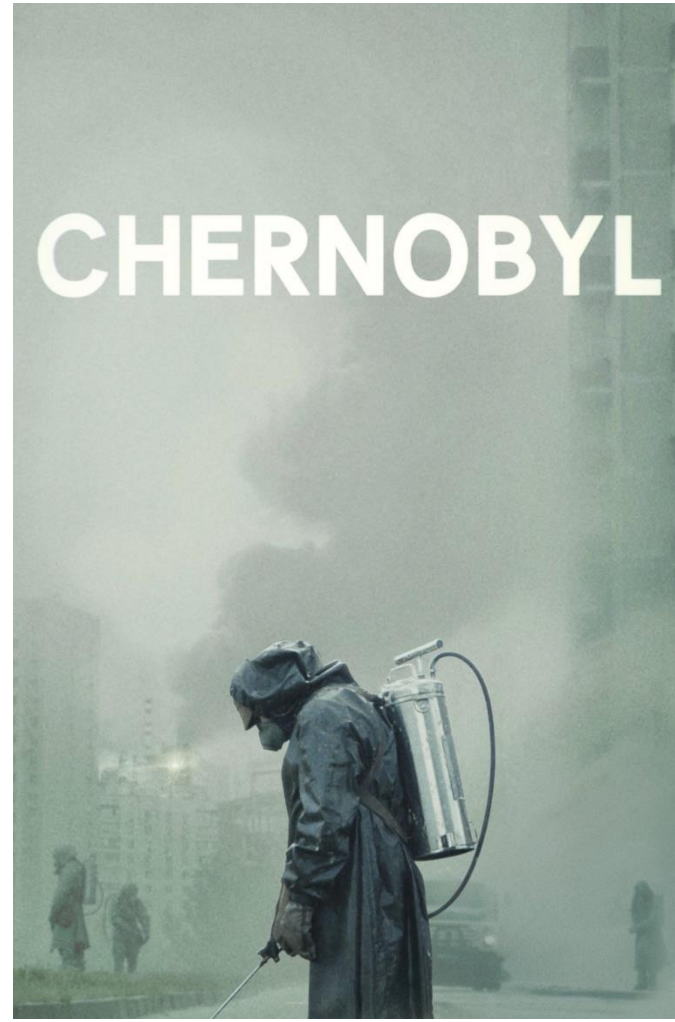


Critical Infrastructure Threat Landscape

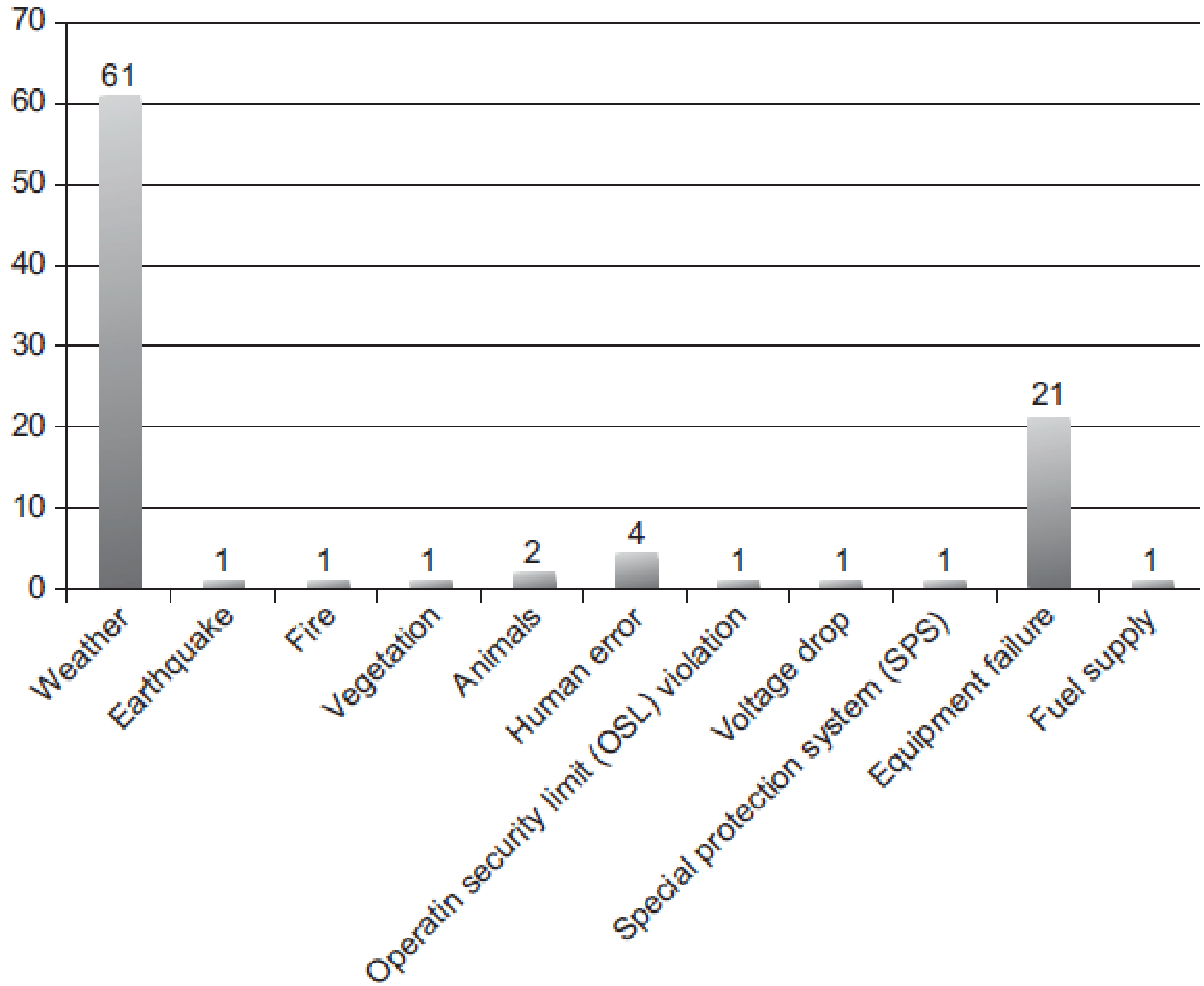


Security issues in Smart Grid





Security issues in Smart Grid



Major causes for power disturbances

Security issues in Smart Grid

- **Naturally occurring threats**

- Natural threats, such as severe weather and natural disasters, cause more than 50 percent of disturbances in power system
- Ranging from small storms to natural disasters, smart grids will face natural threats that can significantly impact consumers
- Redundancy can be built into most areas of smart grids, but there will still be single points of failure for consumers
- Under the current vision, smart grids will be able to route power from a number of different sources

Security issues in Smart Grid

- **Individual and organizational threats**
- Advanced metering infrastructure (AMI) – Smart Meter and other components of smart grids will allow operators to remotely administer devices in consumer homes
- Additionally, smart devices within consumer’s home area networks (HAN) will allow consumers and potentially utility companies to remotely control electricity usage
- Numerous motives may drive people and organizations to abuse these smart grid functionalities
- From angry neighbors to terrorist organizations, the possibility of gaining control of AMI components, HAN devices, and these functionalities will lead to attacks against smart grids

Security issues in Smart Grid

- **Smart Thieves and Stalkers**
- The vision of the smart grid promises to empower consumers with information regarding their energy consumption
- Consumers will be able to monitor their energy consumption in quasi-real time, such as hourly, whereas consumers are currently informed of their usage on a monthly basis
- One of the desired results is to enable consumers to modify their behaviors in order to reduce their electricity bill
- With access to this kind of information, however, others could use it to enable their malicious acts
- This level of information will greatly aid a thief in burglarizing consumers

Security issues in Smart Grid

- **Hackers**
- The motives for hacking smart grids will cover a broad range
- The common motives of hackers that can be applied to any environment:
    - Intellectual challenge
    - Self-expression and peer recognition
    - Testing computer security
    - Mischief or curiosity
    - Monetary gain
    - Power
    - Vengeance and vindictiveness
    - Attacking the "system" or terrorism

- These motives will still be relevant with smart grids and can impact consumers in new ways

Security issues in Smart Grid

- **Threats from utility companies**
- Utility companies, or more precisely agents of utility companies, will be threats to consumers through intentional or unintentional actions
- From accidents to insider threats, utility company agents may continue to be a cause of power disruptions, privacy leaks, improper billing, and more
- **Accidental threats**
  - Although increased automation will decrease the number of incidents caused by human error, operators, and maintenance, employees will be required to interact with the smart grid
  - Increased training at regular and frequent intervals should decrease the risk of accidents; however, accidents will always remain a threat to the operation and maintenance of smart grids
- **Intentional attacks**
  - Angry employees lashing out in the workplace is not a new concept
  - Negative performance reviews, inadequate compensation, impending layoffs, and arguments with management are common reasons for employees to lash out at their employers, which could indirectly cause negative impact to consumers

Security issues in Smart Grid

- **Threat site and vulnerability**

Location	Vulnerability
Electricity Generators	More external monitoring and dispatching, and Distributed Energy Resources (e.g. Solar and Wind)
Electrical/Grid Control Systems (transmission & distribution)	More digital interfaces, sophisticated SCADA, load balancing, voltage frequency control, monitoring
Smart Meters	More digital connections and customer interfaces
Pricing, Bidding, and Billing Systems	More active generator and customer interfaces & customer privacy issues (including complexity with time of day pricing, and Software as a Service)

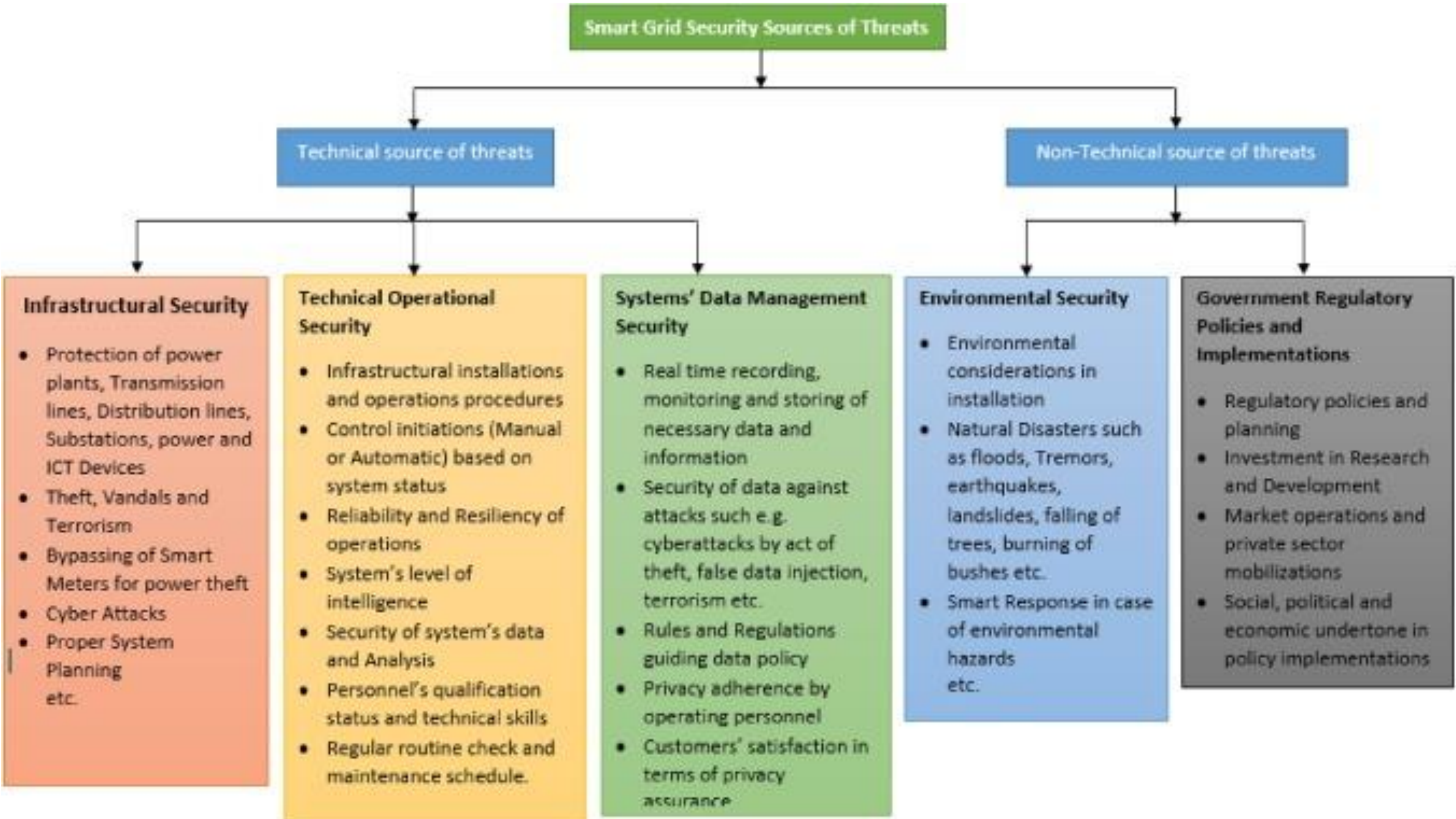
Security issues in Smart Grid

- **Consequences of threats**

- **Loss of grid control** from errors or deliberate tampering with data, complex algorithms, or communications
  - Cascading Failure Modes, blackouts
  - Extended problems with electric grids crossing national borders
  - Attack via dispersed Distributed Energy Resources (e.g. solar, wind, storage) with insufficient cyber security
- **False data injection** into pricing and demand systems
  - Market manipulation
- Economic impact to the economy
- Insurance liability
- Loss of reputation and diminished credit of electric utility
- Loss of revenue of the electric utility
- Lawsuits against the electric utility and its suppliers

Security issues in Smart Grid

- **Countermeasures against threats**



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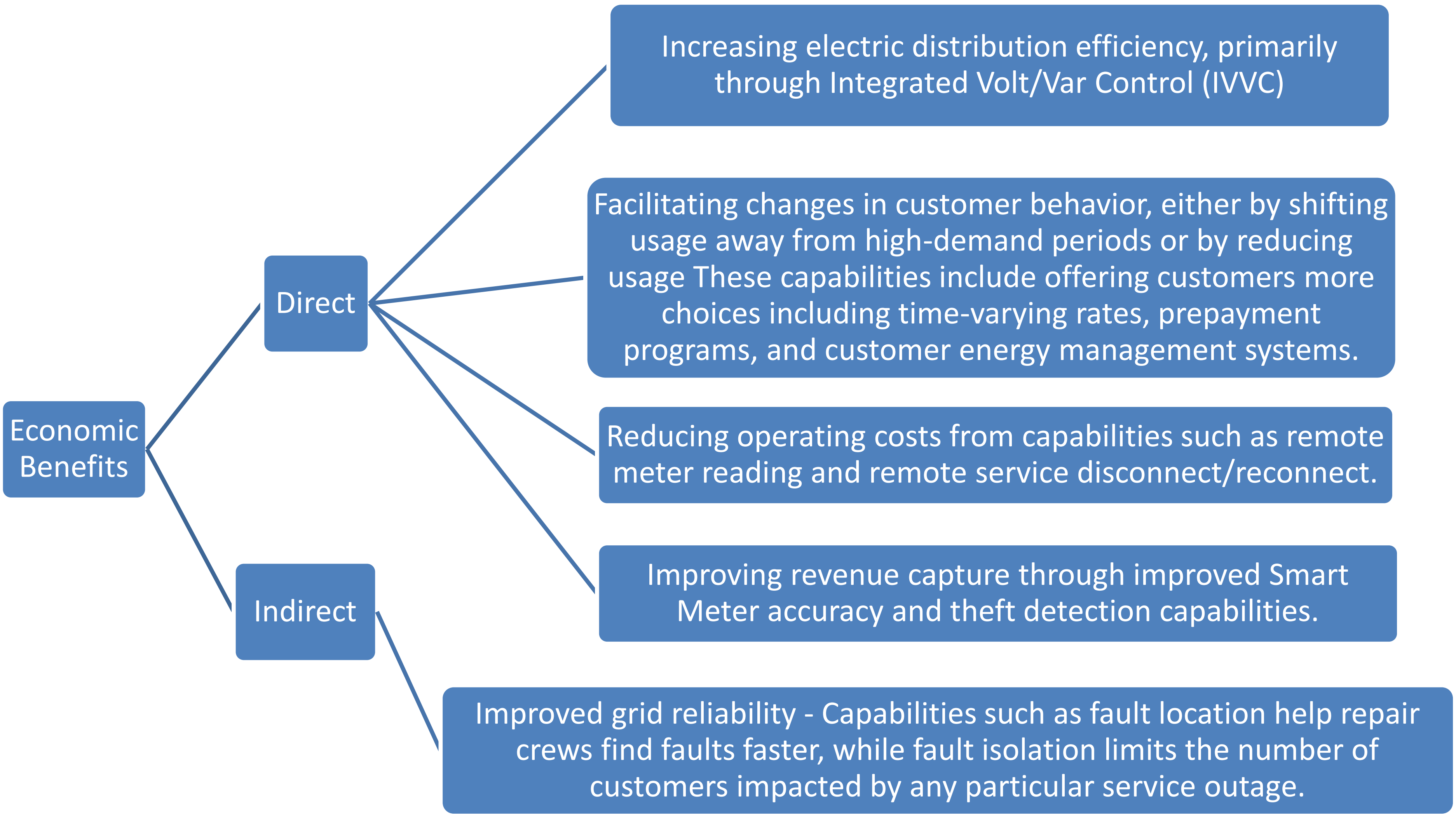

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Asset Management System (AMS)

Decreasing unmanaged risk

- Increase device health, safety & environmental conditions
- Manage complexity and interoperability
- Lessen sweating of assets

Achieving sustainability

- Through the assurance of having adequate infrastructure, human, and financial resources
- Lower cost of maintenance

Monitor

- Access the health of the plant assets by monitoring asset condition periodically in real-time

Predict

- Identify potential problems before they actually occur and affect or cause to a catastrophic failure

Analyze

- Identification of problem severity, possible causes, and corrective actions to help the operators decide the most suitable critical actions

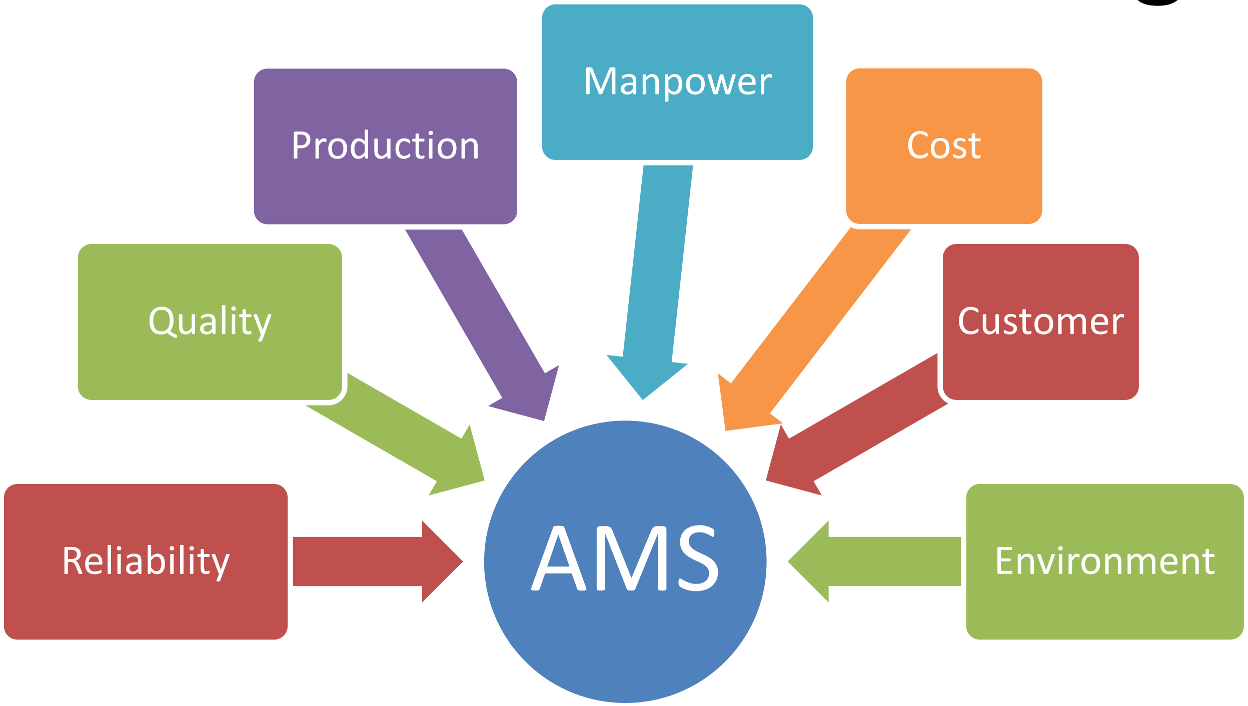
Prevent

- Provides solutions to protect equipment against catastrophic damage in case of abnormal conditions

Asset Management in Smart grid

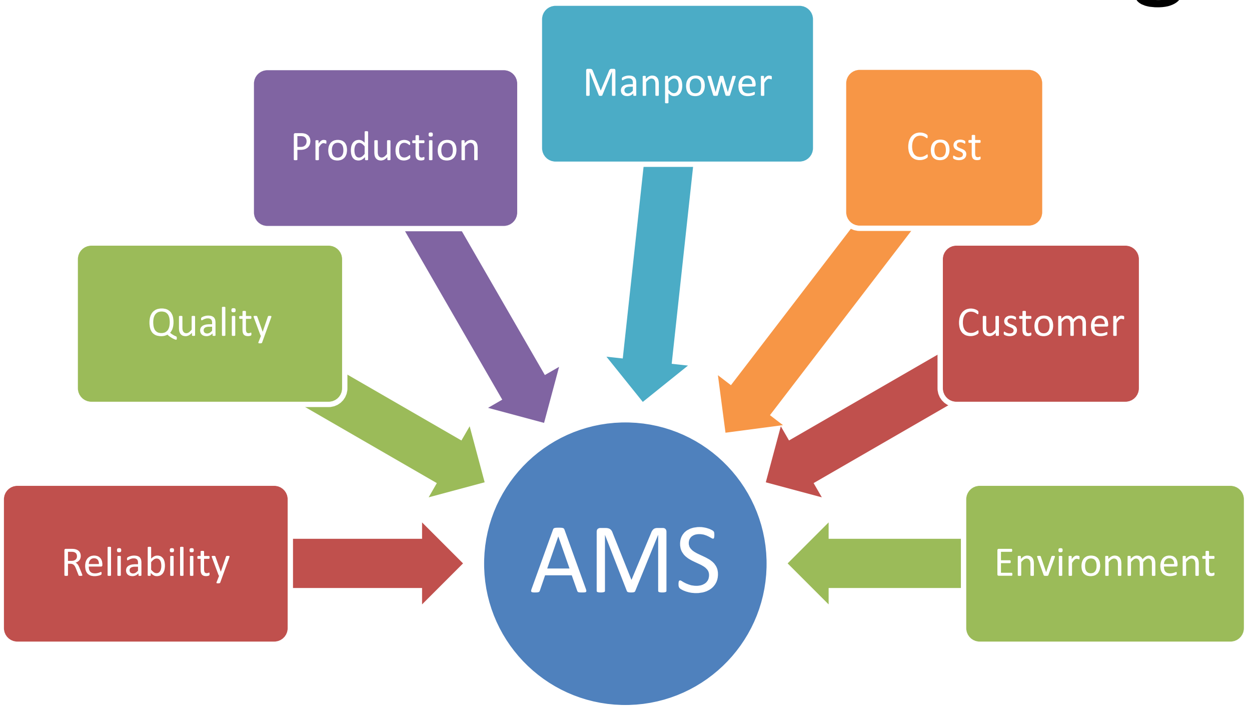
- AMS is a hardware-cum-software application used to manage and maintain assets in a plant for their efficient and optimum utilization
- It enables the plant to achieve the excellence in operation and maintenance
- There are many AMSs deployed for different applications, which facilitate continuous monitoring, prediction, analysis, and error reporting of an asset’s functioning at the plant level

Drivers for AMS in Smart grid



- **Reliability** is a competitive business issue, which effects success of plant's run
  - Any unintended shutdowns will have considerable impact on the plant' productivity
- **Quality** is an endurance point in the commercial market for better products and sales
- Increased **production** on aged assets delays new capital investment though sustaining the existing production

Drivers for AMS in Smart grid



- Reduction of **manpower** demands to do more with less
- **Cost** reductions motivates operations and maintenance
- More stringent requirements of the **customers** on product specifications, precision, reliability, etc., affects the business
- **Environmental safety** concerns have become an overall plant's issue to take suitable management decisions

Users of AMS in Smart grid

Hardware engineers

- Configuring and setting up devices
- Device commissioning during start-up
- Assisting maintenance with troubleshooting
- Assisting operation with problem solving

Operators

- Device diagnostics
- Status checks
- Device information reference for running the plant

Maintenance technicians

- Performing routine maintenance
- Checking device status and troubleshooting
- Device database upload (history) for archived reference
- Device replacement and need setup reconfiguration

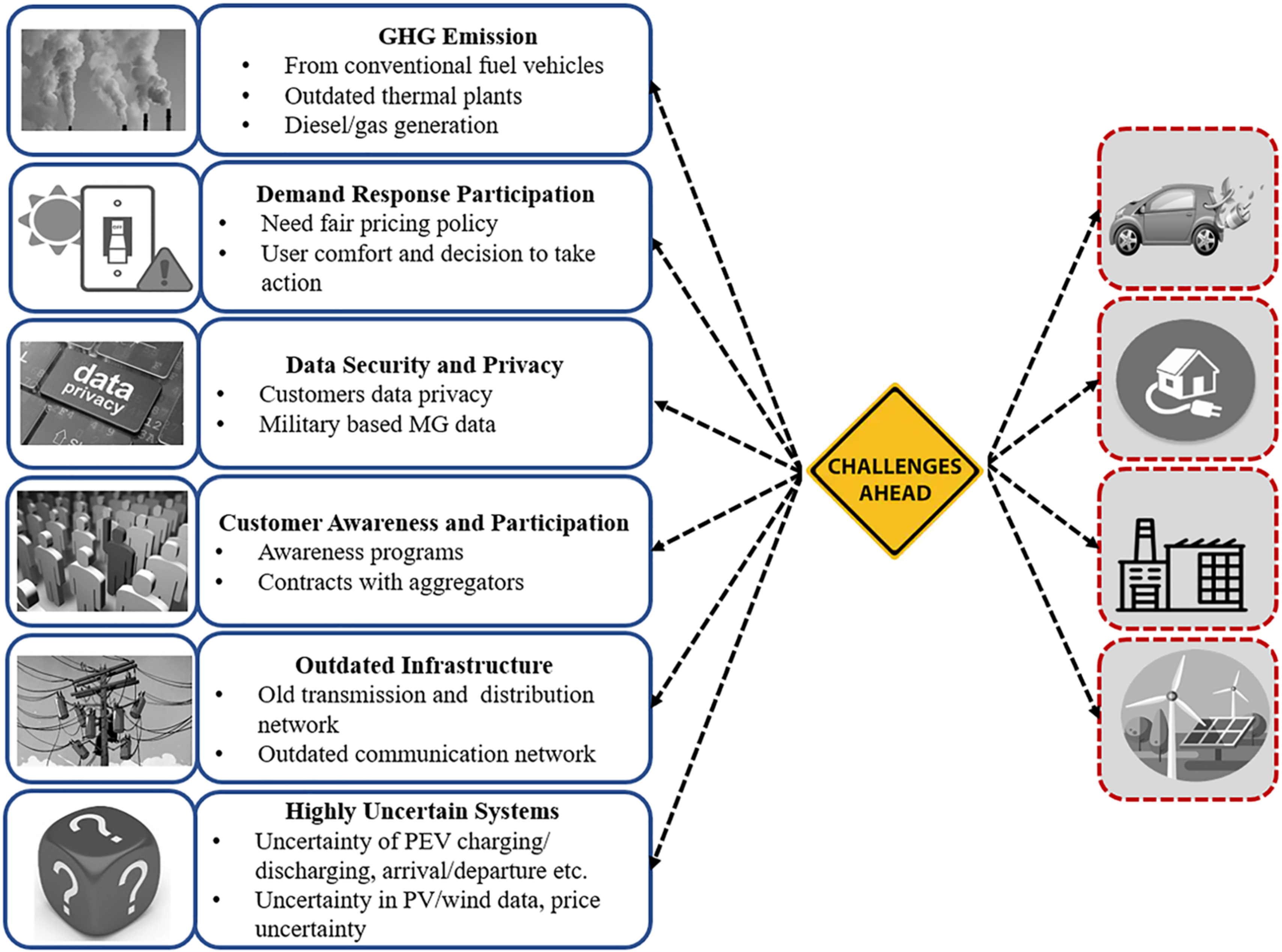
Managers

- Create report and provide access to new users

Electrical engineers

- Configure the electrical assets
- Checking all the electrical connections/ routing
- Generate and check the alarms for system protection
- Schedule the maintenance activities

Challenges of Smart grid



Challenges of Smart grid

Technology	Challenges	Obligations
Self-Healing Action	Security	Exposed to internet attacks (Spams, Worms, virus etc.), question of National security
	Reliability	Failure during natural calamities, system outages and total blackout
Renewable Energy Integration	Wind/Solar Generation	Long-term and un-predictable intermittent sources of energy, unscheduled power flow and dispatch
	Power Flow Optimization	Transmission line congestions and huge investments
	Power System Stability	Decoupling causes system stability issues causes reduced inertia due to high level of wind penetration
Energy storage systems	Cost	Expensive energy storage systems like Ultra-capacitors, SMES, CAES etc.
	Complexity	Complex customary design module and networks
	Non-Flexibility	Unique designs for all individual networks not ease adaptation

Challenges of Smart grid

Technology	Challenges	Obligations
Consumers Motivation	Security	Malware, data intercepting, data corruption, Illegal power handling and Smuggling
	Privacy	Sharing of data cause privacy invasion, etc.,
	Consumer awareness	Corruption and system threats like security and privacy issues
Reliability	Grid Automation	Need of strong data routing system, with secure and private network for reliable protection, control and communication
	Grid Reconfigurati on	Generation-demand equilibrium and power system stability with grid complexity
Power Quality	Disturbance Identification	Grid disturbances due to local faults in grids, load centers or sources
	Harmonics Suppression	System instability during sags, dips or voltage variation such as over-voltages, under-voltages, voltage flickers, etc.