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Smart Grid – Part I

Transforming the Traditional Electrical Grid

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Introduction

- ✓ Advancement of traditional electrical grid
- ✓ Traditional electrical grid
  - ✓ Energy generation is done in centralized power plants
  - ✓ Energy distribution is one directional – from the power plant to the homes or industries.
  - ✓ Monitoring and restoration of grid is done manually
  - ✓ Uni-directional communication
- ✓ Smart Grid –
  - ✓ Achieve high reliability in power systems
  - ✓ A cyber-physical system equipped with sustainable models of energy production, distribution, and usage

What is Smart Grid

- ✓ Smart grid is conceptualized as a planned nationwide network that uses information technology to deliver electricity efficiently, reliably, and securely.
- ✓ Smart grid is also named as –
  - ✓ Electricity with a brain
  - ✓ The energy internet
  - ✓ The electronet
- ✓ According to the definition given by NIST, smart grid is – "*a modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications.*"

Source: https://www.nist.gov/engineering-laboratory/smart-grid/about-smart-grid/smart-grid-beginners-guide

Benefits of Smart Grid

- ✓ Benefits associated with the Smart Grid include:
  - ✓ More efficient transmission of electricity
  - ✓ Quicker restoration of electricity after power disturbances
  - ✓ Reduced operations and management costs for utilities, and ultimately lower power costs for consumers
  - ✓ Reduced peak demand, which will also help lower electricity rates
  - ✓ Increased integration of large-scale renewable energy systems
  - ✓ Better integration of customer-owner power generation systems, including renewable energy systems
  - ✓ Improved security
- ✓ Using smart grid, both the consumers and the energy service providers or stakeholders get benefited.

Benefits of Customers

- ✓ For consumers, the benefit of using smart grid are as follows:
  - ✓ Updated information on their energy usage in real-time
  - ✓ Enabling electric cars, smart appliances, and other smart devices to be charged
  - ✓ Program the smart devices to run during off-peak hours to lower energy bills
  - ✓ Different pricing options

Benefits to Stakeholders

- ✓ For stakeholders, the benefit of using smart grid are as follows:
  - ✓ Increase grid reliability
  - ✓ Reduce the frequency of power blackouts and brownouts
  - ✓ Provide infrastructure for monitoring, analysis, and decision-making
  - ✓ Increase grid resiliency by providing detailed information
  - ✓ Reduce inefficiencies in energy delivery
  - ✓ Integrate the sustainable resources of wind and solar alongside the main grid
  - ✓ Improve management of distributed energy resources, including micro-grid operations and storage management.

Properties of Smart Grid

- ✓ Consumer Participation
  - ✓ Real-time monitoring of consumption
  - ✓ Control of smart appliances
  - ✓ Building Automation
- ✓ Real-time Pricing
- ✓ Distributed Generation
  - ✓ Integration of renewable energy resources
  - ✓ Integration of micro-grid

Properties of Smart Grid (Contd.)

- ✓ Power System Efficiency
  - ✓ Power Monitoring
  - ✓ Asset Management and optimal utilizations
  - ✓ Distribution Automation and Protection

- ✓ Power Quality
  - ✓ Self-Healing
  - ✓ Frequency Monitoring and Control
  - ✓ Load Forecasting
  - ✓ Anticipation of Disturbances

Smart Grid Architecture

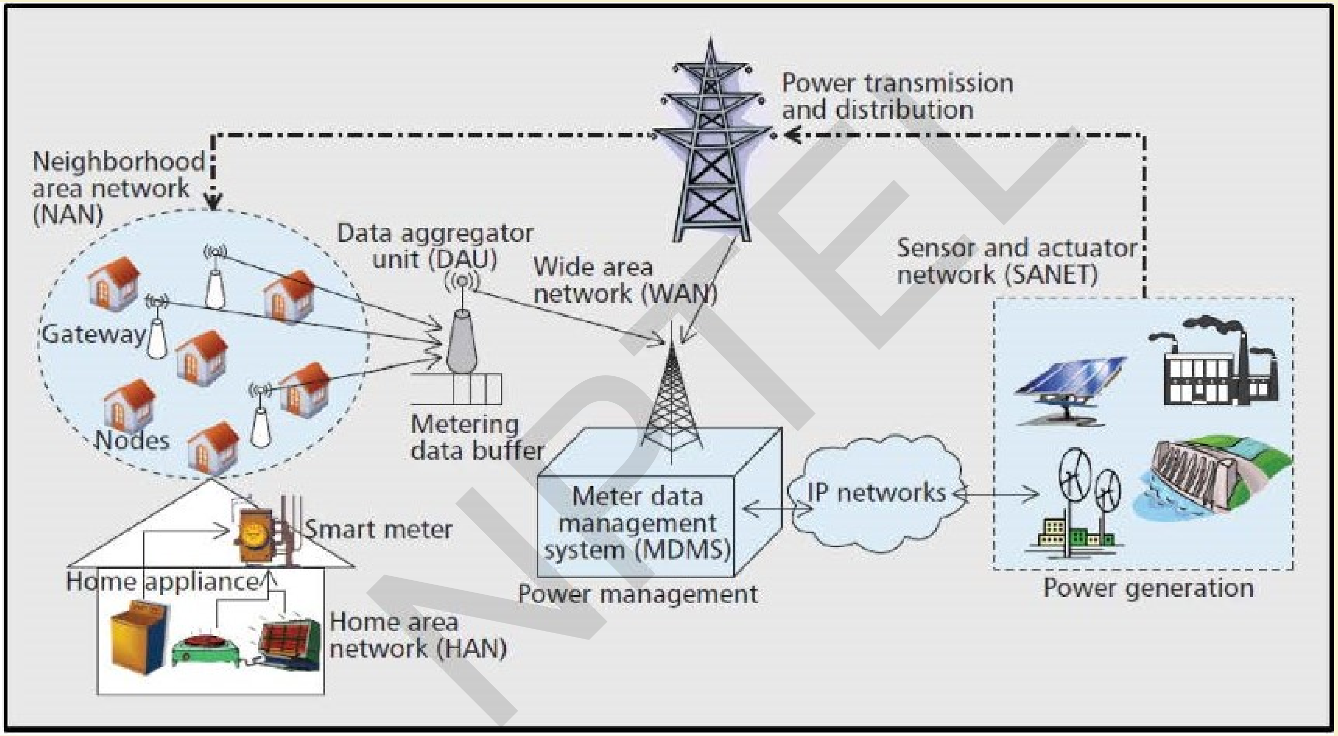
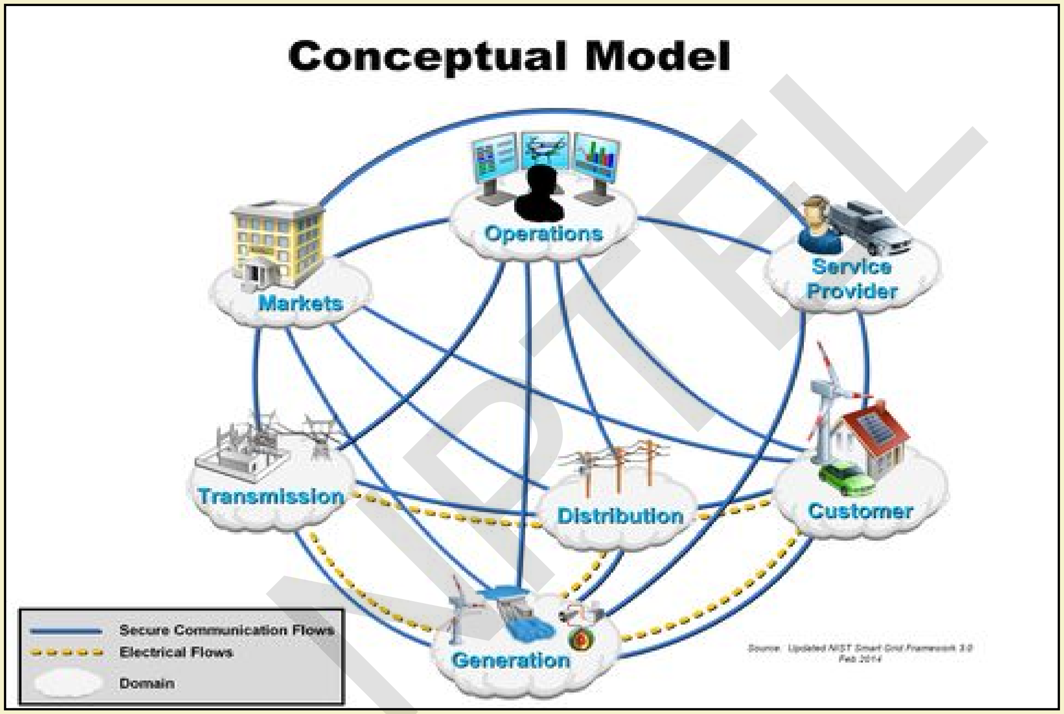


Fig 1: Basic architecture of smart grid [D. Niyato and P. Wang, IEEE CM, 2012]

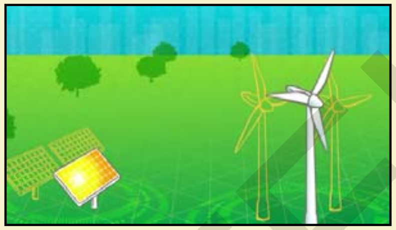
Smart Grid Domains



Source: NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0

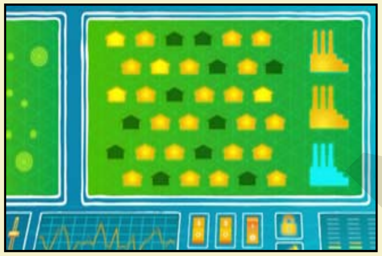
Components of Smart Grid

Smart Home



Renewable Energy

Consumer Engagement



Operation Center

Distribution Intelligence

Plug-in Electric Vehicle

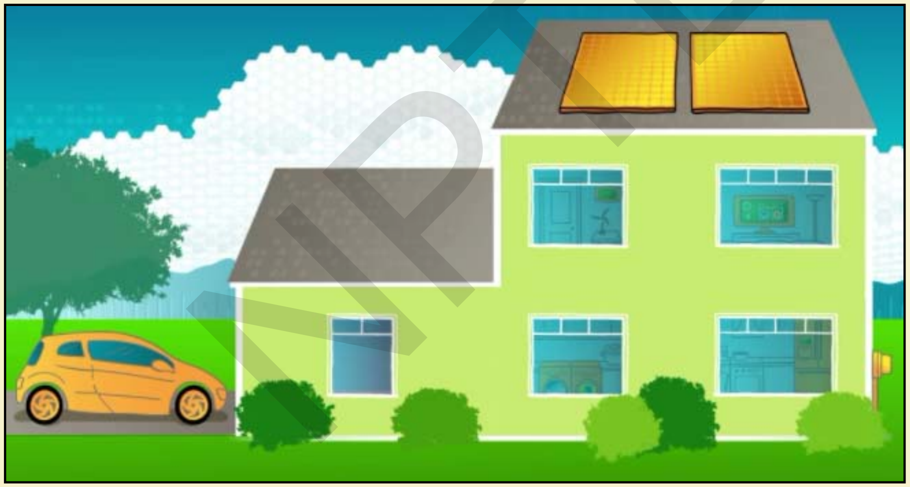
Source: https://www.smartgrid.gov/the_smart_grid/

Smart Home

- ✓ Smart home uses emerging smart grid technologies to save energy, seek out the lowest rates, and contribute to the smooth and efficient functioning of our electric grid
- ✓ The interactive relationship between the grid operators, utilities, and consumers helps in proper functioning of smart grid technologies
- ✓ Computerized controls in smart homes helps to minimize energy use at times when the power grid is under stress from high demand, or even to shift some of their power use to times when power is available at a lower cost, i.e., from on-peak hours to off-peak hours

Smart Home (Contd.)

- ✓ Smart home depends on –
  - ✓ Smart meters and home energy management systems
  - ✓ Smart appliances
  - ✓ Home power generation



Smart Home (Contd.)

- ✓ Smart Meters
  - ✓ Provide the Smart Grid interface between consumer and the energy service provider
  - ✓ Operate digitally
  - ✓ Allow for automated and complex transfers of information between consumer-end and the energy service provider
  - ✓ Help to reduce the energy costs of the consumers
  - ✓ Provides information about usage of electricity in different service areas to the energy service providers

Smart Home (Contd.)

- ✓ Home energy management systems
  - ✓ Allows consumers to track energy usage in detail to better save energy
  - ✓ Allows consumers to monitor real-time information and price signals from the energy service provider
  - ✓ Allows to create settings to automatically use power when prices are lowest
  - ✓ Avoids peak demand rates
  - ✓ Helps to balance the energy load in different area
  - ✓ Prevents blackouts
- ✓ In return, the service provider also may choose to provide financial incentives

Smart Home (Contd.)

- ✓ Smart Appliances
  - ✓ Automated and robust in nature
  - ✓ Response to signals from the energy service provider to avoid using energy during times of peak demand
  - ✓ Include consumer controls to override the automated controls
- ✓ By overriding, the consumer can consume energy as per their requirement, while paying minimum is not ensured

Smart Home (Contd.)

- ✓ Home Power Generation
  - ✓ Power generation system at consumers-end
  - ✓ Rooftop solar electric systems
  - ✓ Small wind turbines
  - ✓ Small hydropower System
  - ✓ Home fuel cell systems – produce heat and power from natural gas
- ✓ Surplus energy generated by the home power generation systems can be fed back into the grid
- ✓ In case of "Islanding", a home can have power from distributed resources, i.e., home power generation systems

Renewable Energy

- ✓ According to the International Energy Agency –
  - ✓ *"Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources."*
- ✓ Reduced environmental pollution
- ✓ Consumers capable of generating energy from renewable energy resources are less dependent on the micro-grid or main grid
- ✓ In addition to that, they can supply surplus amount of energy from the renewable resources and can make profit out of it

Consumer Engagement

- ✓ Consumers can –
  - ✓ Save energy with proper scheduling of smart home appliances
  - ✓ Pay less for consuming energy in off-peak hours

- ✓ Energy service provider gives incentives based on the energy consumption of the consumer and they can save money

- ✓ Consumers' involvement in following ways:
  - ✓ Time-of-Use pricing
  - ✓ Net metering
  - ✓ Financial incentives

Consumer Engagement (Contd.)

- ✓ In Time-of-Use pricing
  - ✓ The consumers are encouraged to consume energy in off-peak hours when the energy load is less
  - ✓ Throughout the day, the energy load on the grids are dynamic
- ✓ In on-peak hours, if the requested amount of energy is higher, it leads to –
  - ✓ Less-efficient energy distribution
  - ✓ More pollution – it depends on the non-renewable energy resource to meet the peak requirement
- ✓ Home energy management system tries to schedule the smart appliances in off-peak hours
  - ✓ To ensure efficient service
  - ✓ To pay less

Consumer Engagement (Contd.)

- ✓ Net metering
  - ✓ It is feasible with the installation of smart meters
  - ✓ Consumers are paid high, if they are supplying excess amount of generated energy to the grid in on-peak hours
  - ✓ The price is less in case of off-peak hours

- ✓ Final bills to be paid by the consumers depends on
  - ✓ The in-flow of energy (from the grid to the consumers-end)
  - ✓ The out-flow of energy (from the consumers-end to the grid)

- ✓ The consumer may get incentives from the energy service provider at the end of the year based on the net metering value

Consumer Engagement (Contd.)

- ✓ Financial Incentives
  - ✓ Energy service provider offers some financial incentives for the consumers' participation
  - ✓ Incentives for shifting operation of appliances to the off-peak hours
  - ✓ Incentives for using stored energy at the battery installed at the consumers-end or at the plug-in hybrid electric vehicles (PHEVs)
- ✓ Smart grid enables consumers engagement to a large extend
- ✓ Consumers get financial incentives by different means from the energy service providers
- ✓ Energy service providers maintain efficient and load balancing energy distribution

Thank You!!

Smart Grid – Part II

Transforming the Traditional Electrical Grid

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Operation Centers

- ✓ Drawbacks of traditional operation centers
  - ✓ Tries to make sure the amount of generated energy is getting used
  - ✓ The grid is unstable, if the grid voltage drops due to excess energy generation
  - ✓ Limited control capabilities
  - ✓ No means to detect oscillation which leads to blackout
  - ✓ Limited information about the energy flow through the grid
- ✓ Smart grid
  - ✓ Provides information and control on the transmission system
  - ✓ Makes the energy grid more reliable
  - ✓ Minimize the possibility of widespread blackouts

Operation Centers (Contd.)

- ✓ For monitoring and controlling the transmission System in smart grid, phasor measurement unit (PMU) is used
- ✓ PMU samples voltage and current with a fixed sample rate at the installed location
- ✓ It provides a snapshot of the active power system at that location
- ✓ By increasing the sampling rate, PMU provides the dynamic scenario of the energy distribution system
- ✓ PMU helps to identify the possibility of blackout in advance
- ✓ Multiple PMUs form a phasor network
- ✓ Collected information by the phasor network is analyzed at centralized system, i.e., Supervisory Control And Data Acquisition (SCADA) system

Operation Centers (Contd.)

- ✓ Self-healing of grid
  - ✓ Dampen unwanted power oscillations
  - ✓ Avoid unwanted flows of current through the grid
  - ✓ Reroute power flows in order to avoid overloading in a transmission line
  - ✓ This is part of distribution intelligence
- ✓ Demand side energy distribution
  - ✓ Energy supply is done based on the requirement of the consumers
  - ✓ The consumers pay according the consumed energy and price decide by the energy service provider at that time
- ✓ In smart grid, the energy distributors can form coalition and serve the energy requirement in a specific geographic location

Distribution Intelligence

- ✓ Distribution intelligence means the energy distribution systems equipped with smart IoT devices
- ✓ Along with smart meters, distribution intelligence can –
  - ✓ Identify the source of a power outage
  - ✓ Ensure power flow automatically by combining automated switching
  - ✓ Optimize the balance between real and reactive power
- ✓ Reactive power:
  - ✓ Devices that store and release energy
  - ✓ Cause increased electrical currents without consuming real power
- ✓ Intelligent distribution System
  - ✓ Maintains the proper level of reactive power in the System
  - ✓ Protect and control the feeder lines

Plug-In Electric Vehicles

- ✓ Smart Grids have the infrastructure needed to enable the efficient use of plug-in electric vehicle (PEVs)
- ✓ Using PEVs –
  - ✓ Reduce dependency on oil
  - ✓ No pollution when running on electricity
- ✓ PEVs rely on power plants to charge their batteries
- ✓ Energy service provider encourages the consumers to charge batteries of PEVs in off-peak hours
- ✓ PEVs also can be used as an energy source in on-peak hours
- ✓ PEVs get incentives from energy service provider for providing energy to the grid through discharging

Smart Grid Communication

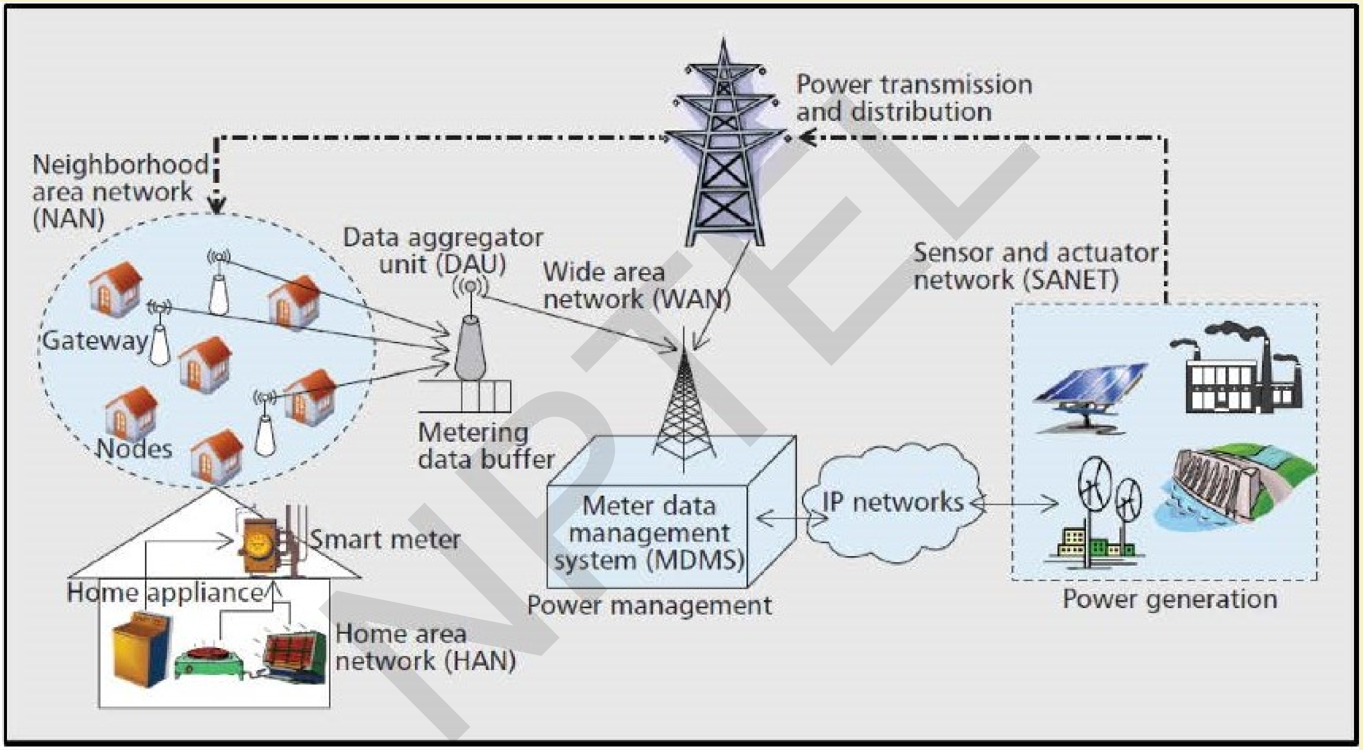


Fig 2: Smart Grid Communication[D. Niyato and P. Wang, IEEE CM, 2012]

Smart Grid Communication (Contd.)

- ✓ Components for smart grid communication are as follows:
  - ✓ Smart Home Appliances
  - ✓ Smart Meters
  - ✓ Gateways
  - ✓ Data Aggregator Units (DAUs)
  - ✓ Meter Data Management Systems (MDMSs)
- ✓ Different networks associated with smart grid communication
  - ✓ Home Area Networks (HANs)
  - ✓ Neighborhood Area Networks (NANs)
  - ✓ Wide Area Networks (WANs)
  - ✓ IP Networks
  - ✓ Sensors and Actuators Networks (SANETs)

Smart Grid Communication (Contd.)

- ✓ For Smart Home Appliances, the available protocol are as follows:
- ✓ C-Bus:
  - ✓ Data Rate: 3500 bits/sec
  - ✓ Able to handle cable lengths upto 1000 m
- ✓ DECT
  - ✓ Data rate: 64000 bits/sec
  - ✓ Operates in 1880 – 1930 MHz
- ✓ EnOcean
  - ✓ Data rate: 9600 bits/sec
  - ✓ Operates in 902 MHz in North America
- ✓ Universal Power line Bus
  - ✓ Data rate: 480 bits/sec
  - ✓ Enable two-way communication protocol

Smart Grid Communication (Contd.)

- ✓ Thread
  - ✓ Data Rate: 20-250 Kbits/sec
  - ✓ IPv6 addressing based 6LowPAN networking protocol
- ✓ Zigbee
  - ✓ Data Rate: 20-250 Kbits/sec
  - ✓ Operates in 2.4 GHz band
  - ✓ IEEE 802.15.4 protocol
  - ✓ Communication range ~100 m
- ✓ Simplified Cable Solution (SCS)
  - ✓ Data rate: 9.6 Kbits/sec
  - ✓ Works on twisted pair
  - ✓ Developed based on OpenWebNet

Smart Grid Communication (Contd.)

- ✓ Smart Meters and Gateways
  - ✓ Each gateway connects few closely located smart meters
  - ✓ Gateways communicate mostly based on WiFi, i.e., IEEE 802.11
  - ✓ Gateways helps in two-way communication
- ✓ Smart meters
  - ✓ Forward the energy consumption information fro the home appliances to the gateways
  - ✓ Forward the billing amount and the control information from the gateways to the home appliances
- ✓ Gateway acts as link between the smart meters and the data aggregator units (DAUs)

Smart Grid Communication (Contd.)

- ✓ Data Aggregator Units (DAUs)
  - ✓ Aggregate the energy consumption or energy request of certain geographical area
  - ✓ Forward the energy consumption information to the centralized coordinator – meter data management system (MDMS)
  - ✓ Maintains a buffer to queue the energy consumption information of the consumers

Smart Grid Communication (Contd.)

- ✓ Meter Data Management Systems (MDMSs)
  - ✓ Act as the centralized coordinator for smart grid communication
  - ✓ Handled by the energy service providers
  - ✓ Part of operation center
  - ✓ Decide the price per unit energy to be paid by the consumers

Smart Grid Security

- ✓ Smart grid is a cyber physical system
- ✓ Following vulnerabilities are there in smart grid
  - ✓ Integrity – credibility of the data collected and transferred over the grid
  - ✓ Availability – accessibility to every grid component as well as to the information transmitted and collected
  - ✓ Dynamic system attacks – based on the previous information same type of request can be replicated by the attacker
  - ✓ Physical threats – physical attack to the smart grid components
  - ✓ Coordinated attacks – cascading failure of systems in smart grid

Smart Grid Security (Contd.)

- ✓ Integrity
  - ✓ Data injection attacks (DIAs)
    - ✓ Manipulation of exchanged data such as sensor readings, feedback control signals, and electricity price signals
    - ✓ Performed by compromising the hardware components (as in the case of Stuxnet), or intercepting the communication links
  - ✓ System Damage
    - ✓ An attacker can manipulate system measurements so that a congested transmission line falsely seems to not have reached its thermal transmission limit
    - ✓ Induce large fluctuations in system dynamics that can lead to tripping additional lines, disconnecting generators, load shedding, or even a system blackout

Smart Grid Security (Contd.)

- ✓ Integrity
  - ✓ Financial benefit
    - ✓ Manipulating the electricity prices
    - ✓ Doing this one can buy energy with lesser price from a service provider and make high profit
  - ✓ Time synchronization attacks
    - ✓ An adversary can manipulate the time reference of the time stamped measured phasors to create a false visualization of the actual system conditions thus yielding inaccurate control and protection actions
    - ✓ Attacks that target PMU time synchronization are known as time synchronization attacks (TSAs)

Smart Grid Security (Contd.)

- ✓ Availability
  - ✓ Accessibility unavailable to every grid component as well as to the information transmitted and collected, whenever needed
  - ✓ Attacks compromising this availability are known as denial of service (DoS) attacks
  - ✓ Block key signals to compromise the stability of the grid and observability of its states
  - ✓ Manipulating generation-load balance

Smart Grid Security (Contd.)

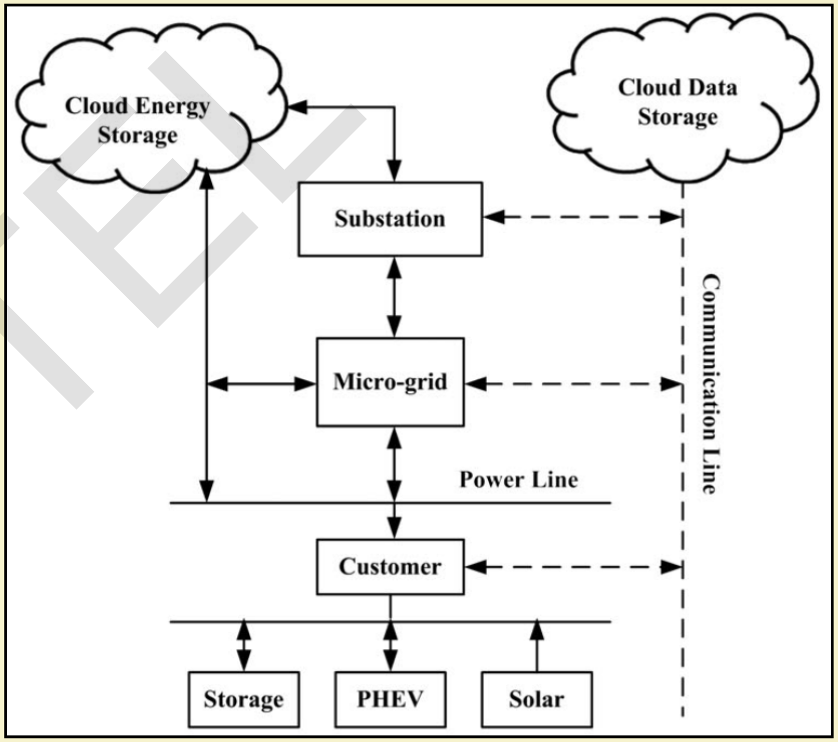
- ✓ Dynamic System Attacks
  - ✓ Replay attacks (RAs)
    - ✓ Injects input data in the system without causing changes to the measurable outputs
  - ✓ In RAs –
    - ✓ Compromises sensors, monitors their outputs
    - ✓ Learns the outputs and repeats them while injecting its attack signal
  - ✓ Dynamic data injection attacks (D-DIA)
    - ✓ Uses knowledge of the grid's dynamic model to inject data that causes unobservability of unstable poles
    - ✓ Can lead to a system collapse
  - ✓ Covert attack
    - ✓ Closed loop version of replay attacks

Smart Grid Security (Contd.)

- ✓ Physical Threats
  - ✓ Attacks a physical component such as a generator, substation, or transmission line is prominent
  - ✓ Physical manipulation of smart meters for energy theft purposes
- ✓ Coordinated Attacks
  - ✓ Power system typically incorporates robustness measures
  - ✓ An attack leading to the failure of one or few components
  - ✓ Exploit the dense interconnections between grid components to launch simultaneous attacks of different types targeting various components

Smart Grid and Cloud Applications

- ✓ In smart grid, cloud applications take a lead in several aspects
  - ✓ Energy management
  - ✓ Information management
  - ✓ Security



S. Bera, S. Misra, and J. J. P. C. Rodrigues, “Cloud Computing Applications for Smart Grid: A Survey,” IEEE Transactions on Parallel and Distributed Systems, vol. 26, no. 5, pp. 1477–1494, May 2015.

Energy Management and Cloud Application

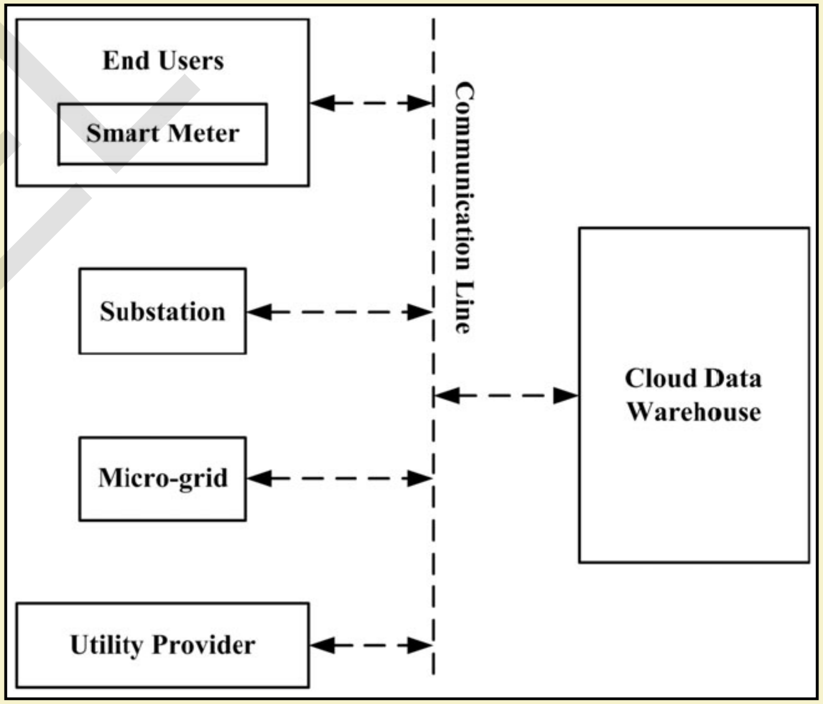
- ✓ The energy management in smart grid can be more efficient by using cloud applications
  - ✓ Cloud-Based Demand Response for fast response times in large scale deployment
  - ✓ Two cloud-based demand response models are proposed as follows:
    - ✓ Data-centric communication and
    - ✓ Topic-based group communication
- ✓ With the integration of cloud, requests from customers are scheduled which are to be executed depending on the available resources, priority, and other applicable constraints
- ✓ Incoming jobs from users are scheduled according to their priority, available resources, and applicable constraints

Energy Management and Cloud Application (Contd.)

- ✓ Integrating cloud computing applications for micro-grid management in the form of different modules such as infrastructure, power management, and service
- ✓ The number of supported customers increases
- ✓ With cloud application, integrate and analyze information streaming from multiple smart meters simultaneously can be done, in order to balance the real-time demand and supply curves
- ✓ Real-time energy usage and pricing information can be shared
- ✓ Mobile agent can be used to monitor power system using cloud computing platform due to the smart grid's heterogeneous architecture

Information Management and Cloud Application

- ✓ Information processing in smart grid fit well with the computing and storage mechanisms available for cloud applications
- ✓ Information from different components, and the supply and demand state conditions can be shared with the help of cloud computing
- ✓ Real-time distributed data management and parallel processing of information can be utilized using smart grid data cloud application

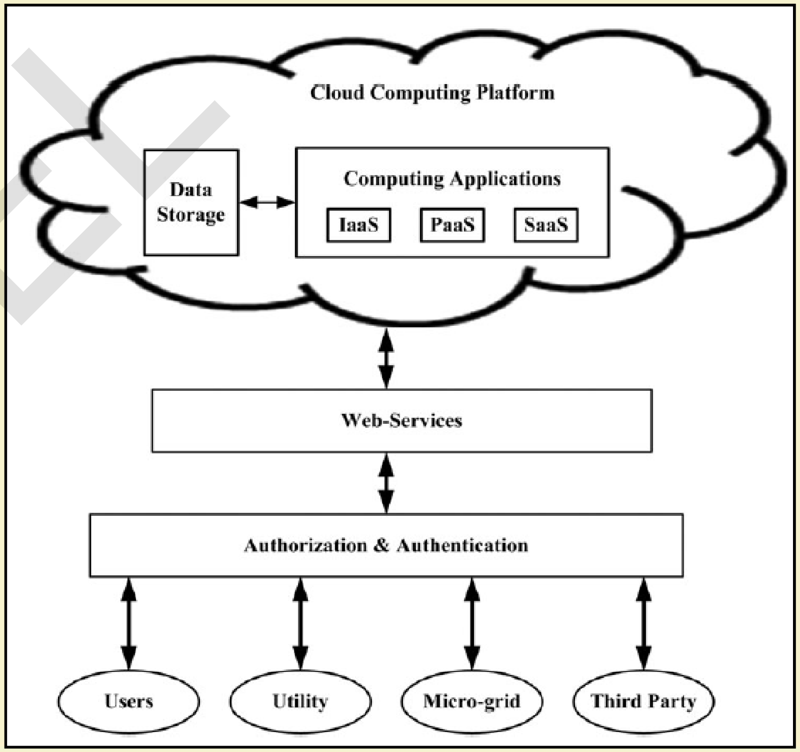


Information Management and Cloud Application (Contd.)

- ✓ With the flexibility of cloud computing, information is retrieved from the data cloud more conveniently in smart grid
- ✓ Dynamic pricing mechanism in smart grid is feasible with the use of cloud application
- ✓ Cloud computing services are used as a dynamic data centers to store the real-time information from the smart meters
- ✓ Use of multi-mobile agent combined with cloud computing for profitable smart grid operation
- ✓ Interactive cooperation using cloud services to support multiple customers and multiple energy sources for large-scale development of smart grid for energy management

Security in Smart Grid and Cloud Application

- ✓ An electric power information security and protection system can be developed using based on cloud security
- ✓ Private cloud platforms are suitable for scaling out and processing millions of data from users
- ✓ Using the cloud computing platform, the electrical utilities can quickly and effectively deal with malicious software



Security in Smart Grid and Cloud Application (Contd.)

- ✓ Security and protection system for electrical power
  - ✓ Servers act as cloud and take decision according to the clients' data
- ✓ Privacy issue in smart grid
  - ✓ Quickly and effectively deal with malicious software with the implementation of cloud computing applications
- ✓ Data storage security for distributed verification in smart grid using cloud application
- ✓ Real-time data can be analyzed and estimated using cloud in smart grid
- ✓ Cloud-based information privacy scheme can be used for smart grid data privacy

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Thank You!!