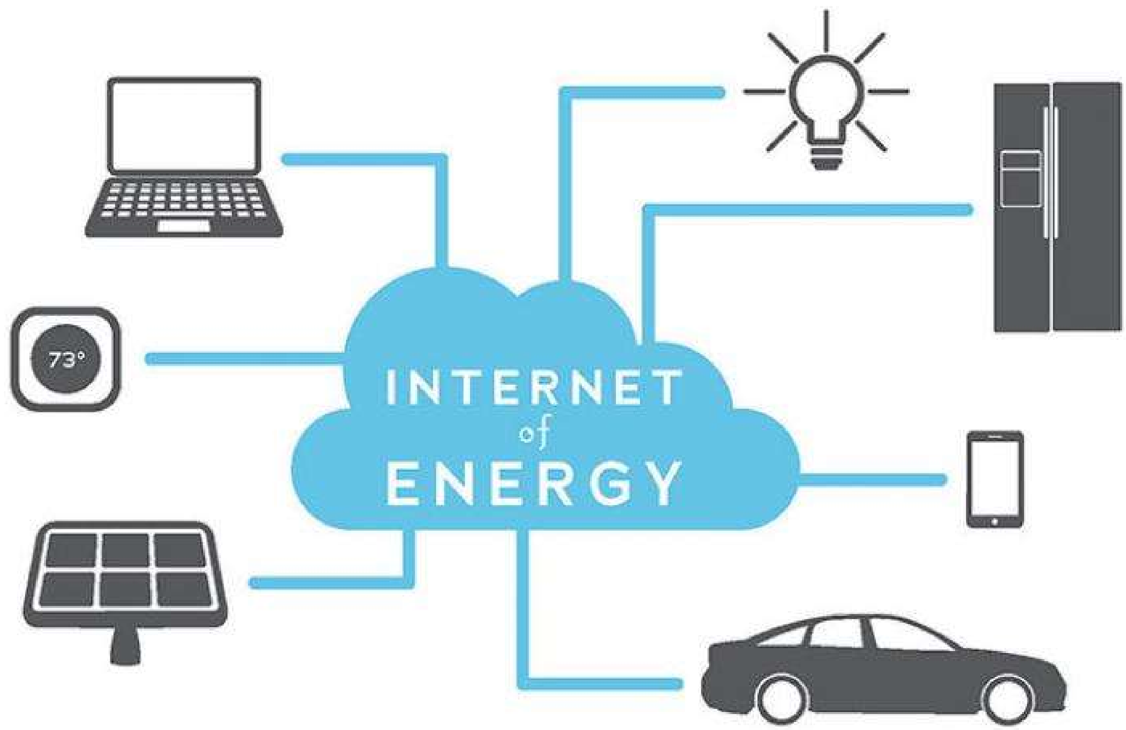
Internet of Things and Applications

Course Code: EE6434D

Module 4



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What is smart grid?

Definition by National Institute of Standards and Technology (NIST), USA:

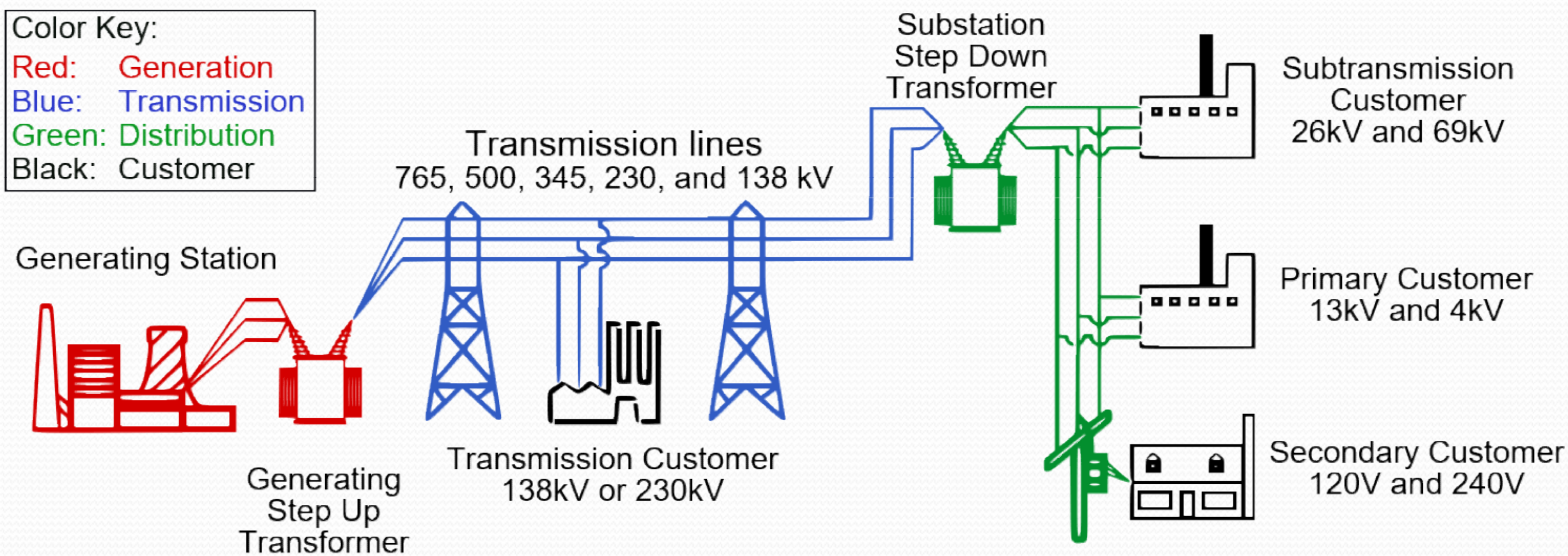
A modernized grid that enables bidirectional flows of energy and uses two-way communication and control capabilities that will lead to an array of new functionalities and applications.

IEEE:

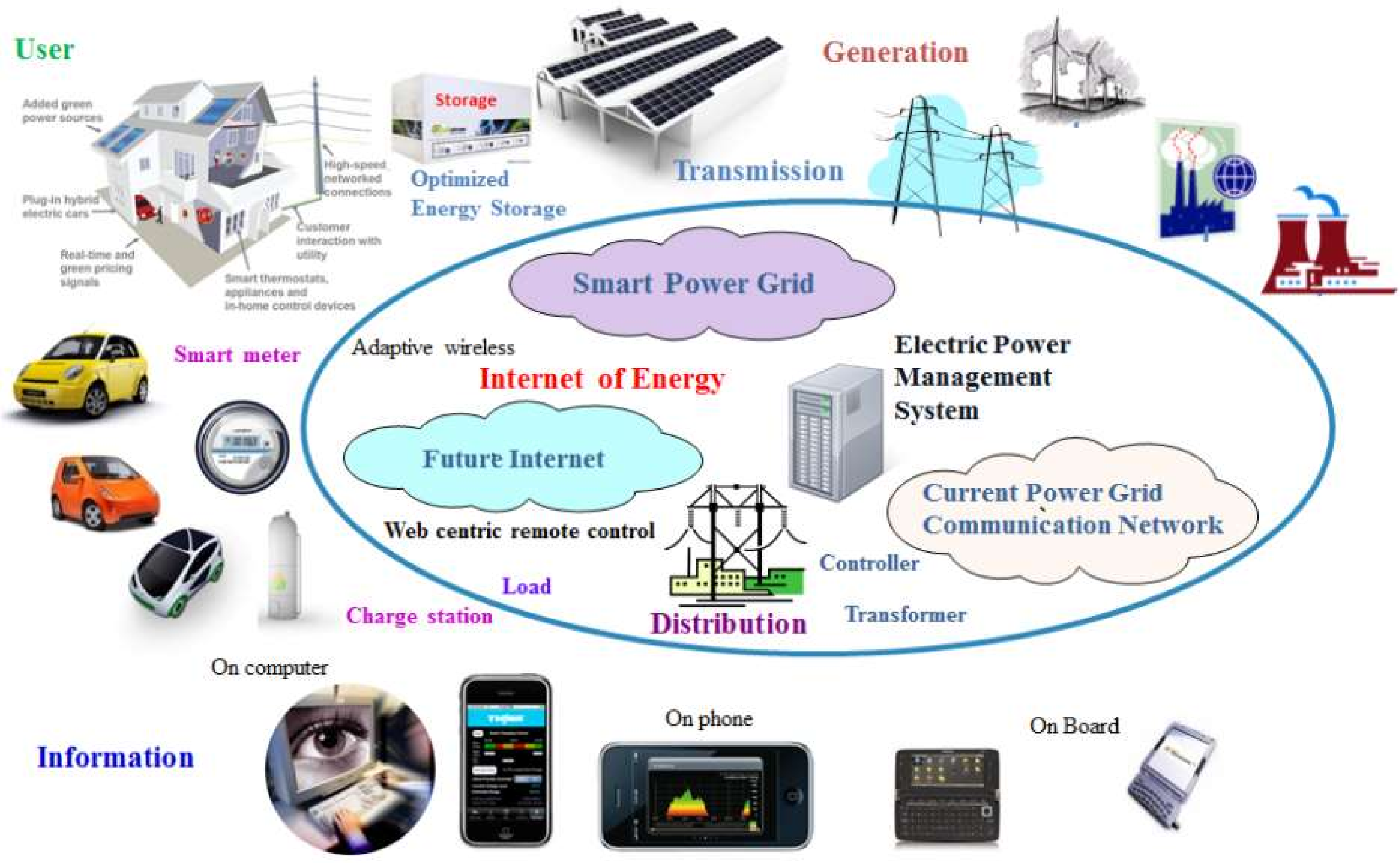
- ✓ Smart grid is a large 'System of Systems', where each functional domain consists of three layers: (i) the power and energy layer, (ii) the communication layer, and (iii) the IT/computer layer.
- ✓ Layers (ii) and (iii) above are the enabling infrastructure that makes the existing power and energy infrastructure 'smarter'.

Need for smart grid

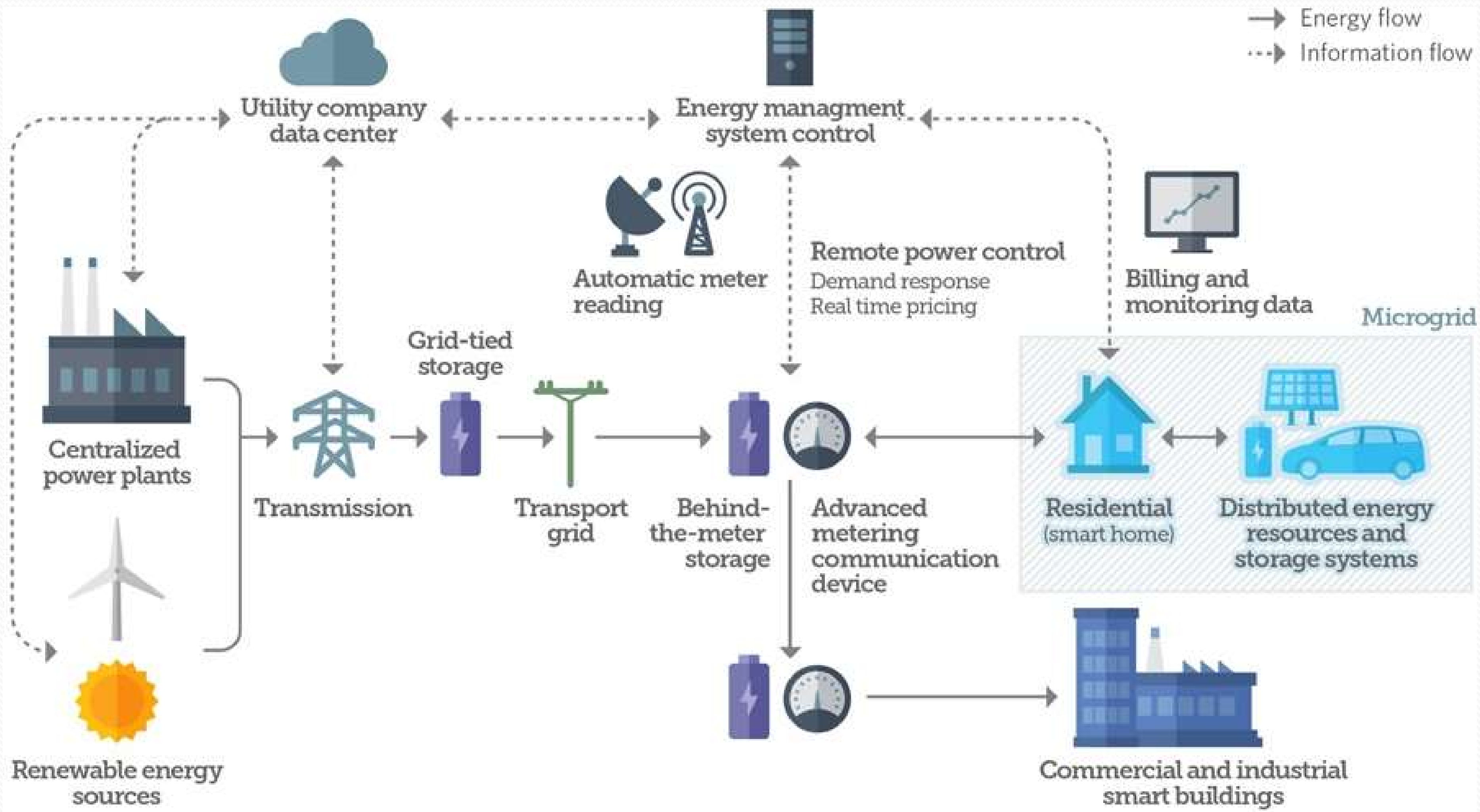
Power system in earlier days



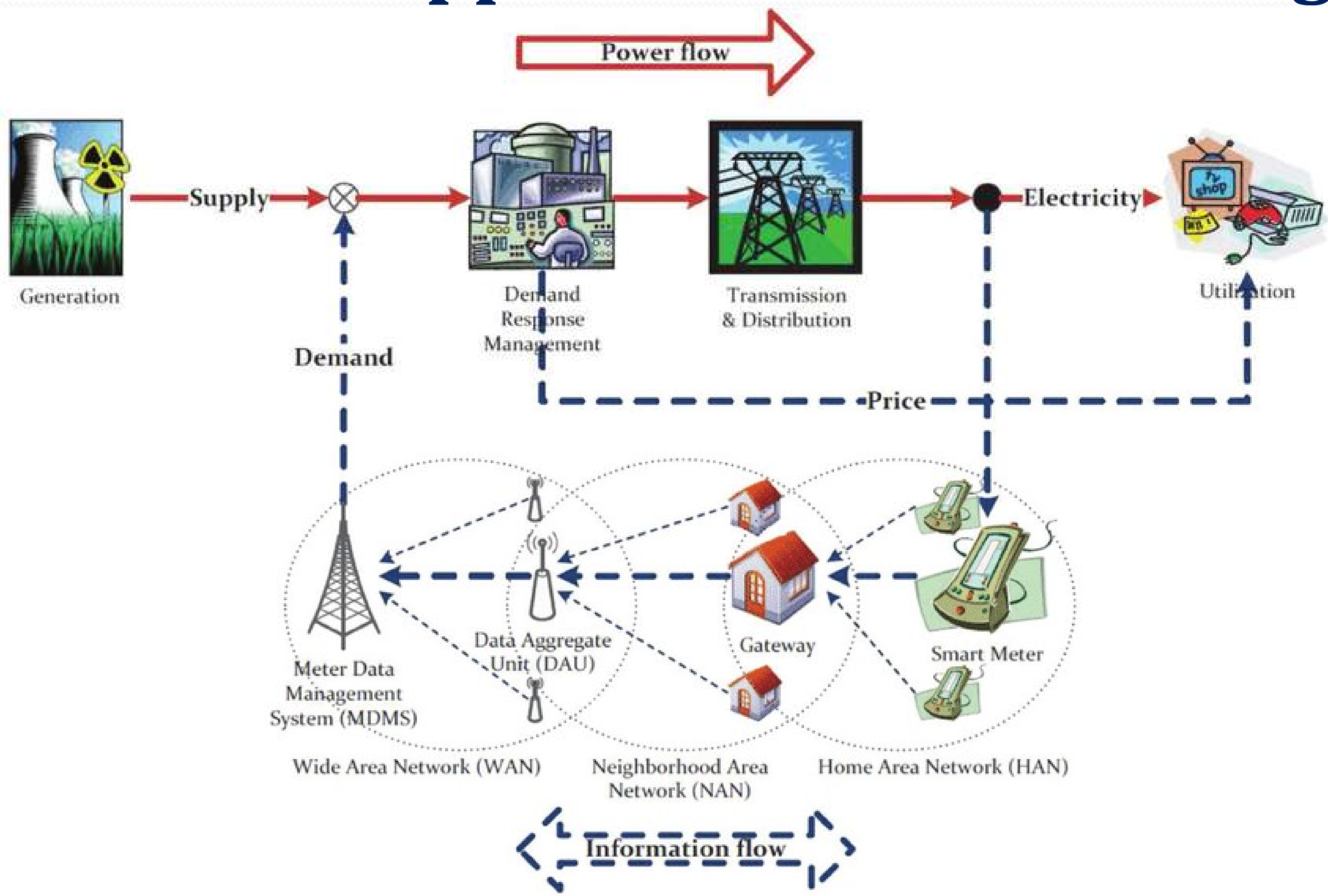
Need for IoE in smart grid



Generalized Approach of IoT to smart grid



Generalized Approach of IoT to smart grid



Characteristics of Modern Power Systems

- ✓ Wide geographical spread (due to typical large distance between major load centres and conventional sources of energy).
- ✓ Large number of interconnections (due to political, economic, environmental, reliability, and stability issues).
- ✓ Rapid growth in the demand of electricity (due to increase in population, standard of living, development of townships).
- ✓ Power system components are being operated closer to their designed limits (more investment needed in the electrical infrastructure).
- ✓ High penetration of renewable energy sources (intermittency, relay coordination, power quality, system stability).
- ✓ Competitive electricity market (needs real time monitoring and strict regulation).

IoE in Generation side

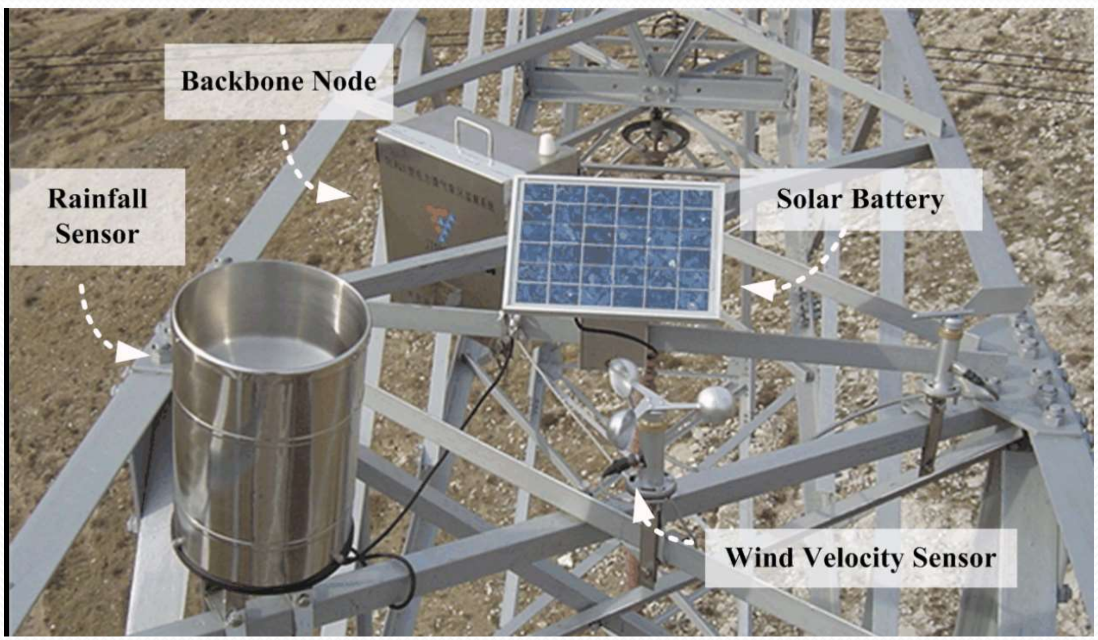
- ✓ Co-existence of various types of renewable and non-renewable generating technologies, such as coal, hydro, nuclear, solar, biomass, geothermal, etc.
- ✓ System operator has to coordinate the operation of the generation plants, and ensure the stable and secure operation of the system.
- ✓ Wide-area measurement system (WAMS) enabled by communication technologies need to be used to control the operation of the generating stations. WAMS based power system stabilizer is one such example.
- ✓ Communication infrastructure needs to be in place between the generating facilities and the system operator, electricity market, and the transmission system.

IoE in Transmission

- ✓ Energy-efficient transmission network will carry the power from the bulk generation facilities to the power distribution systems.
- ✓ Communication interface exists between the transmission network and the bulk-generating stations, system operator, power market, and the distribution system.
- ✓ The transmission network needs to be monitored in real-time, and protected against any potential disturbance.
- ✓ The power flow and voltage on the lines need to be controlled in order to maintain stable and secure operation of the system.
- ✓ An important task of the system operator is to ensure optimal utilization of the transmission network, by minimizing the losses and voltage deviations, and maximizing the reliability of the supply.

IoT enabled Real Time Monitoring on Transmission System

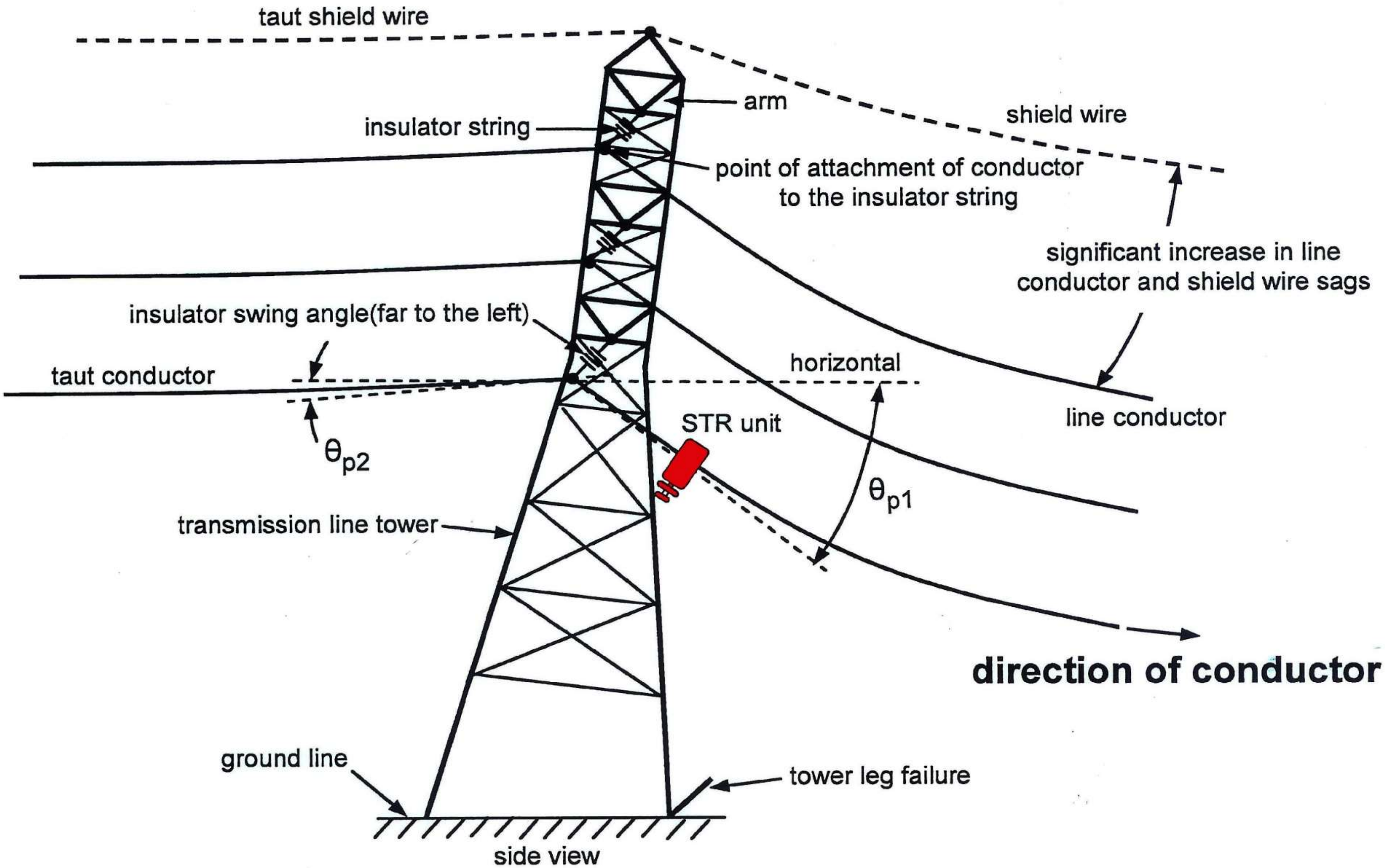
- ✓ Transmission tower leaning:
- ✓ Conductor galloping:
- ✓ Wind deviation:
- ✓ Micro-meteorology : The temperature, humidity, wind velocity, sunshine, and rainfall can be recorded by the wireless sensors along the conductor or on the tower.
- ✓ Conductor icing:
- ✓ Wind vibration:
- ✓ Conductor temperature:



Micro-meteorology Sensor

Conductor Temperature Sensor

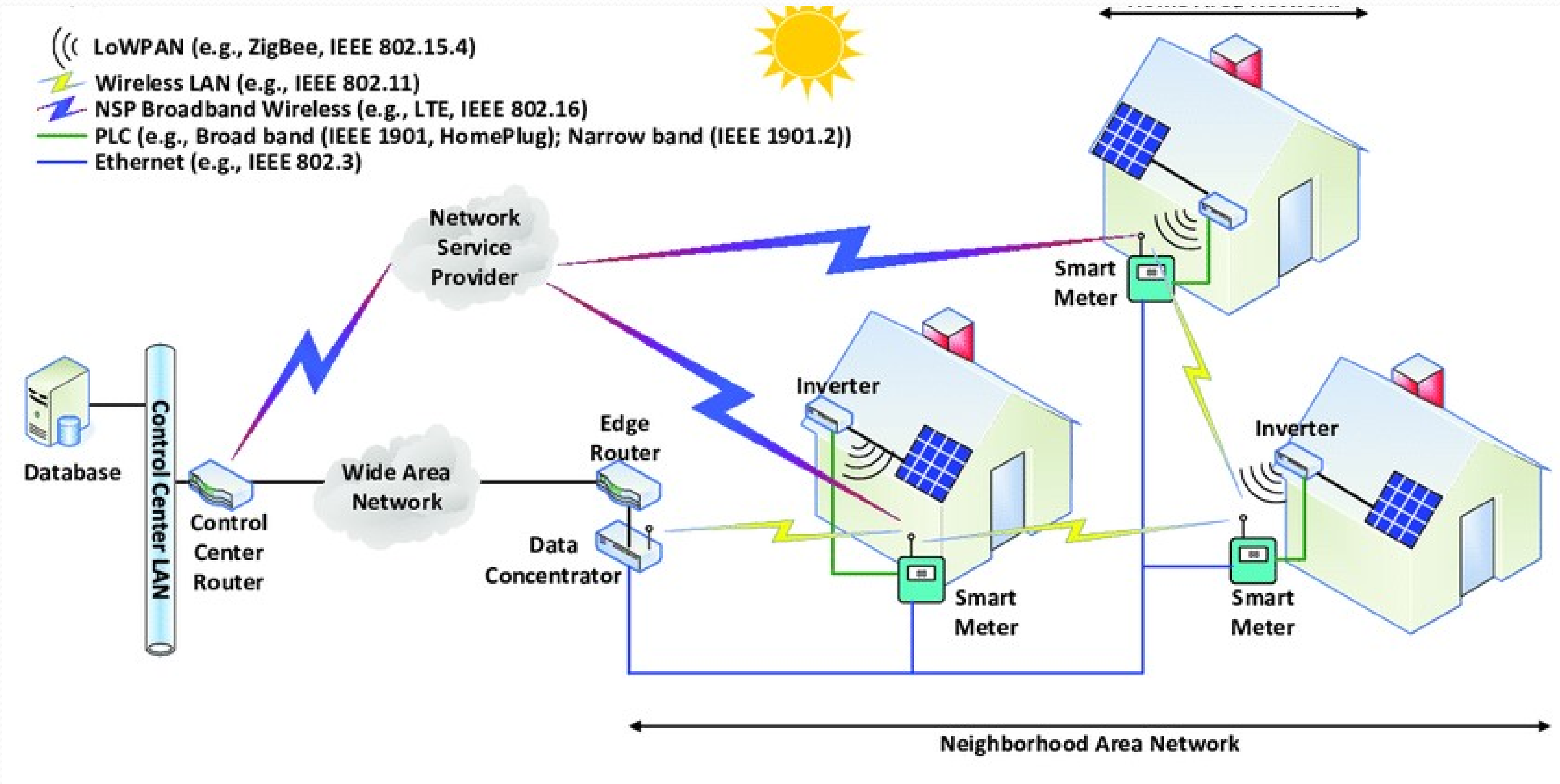
IoT enabled Real Time Monitoring on Transmission System



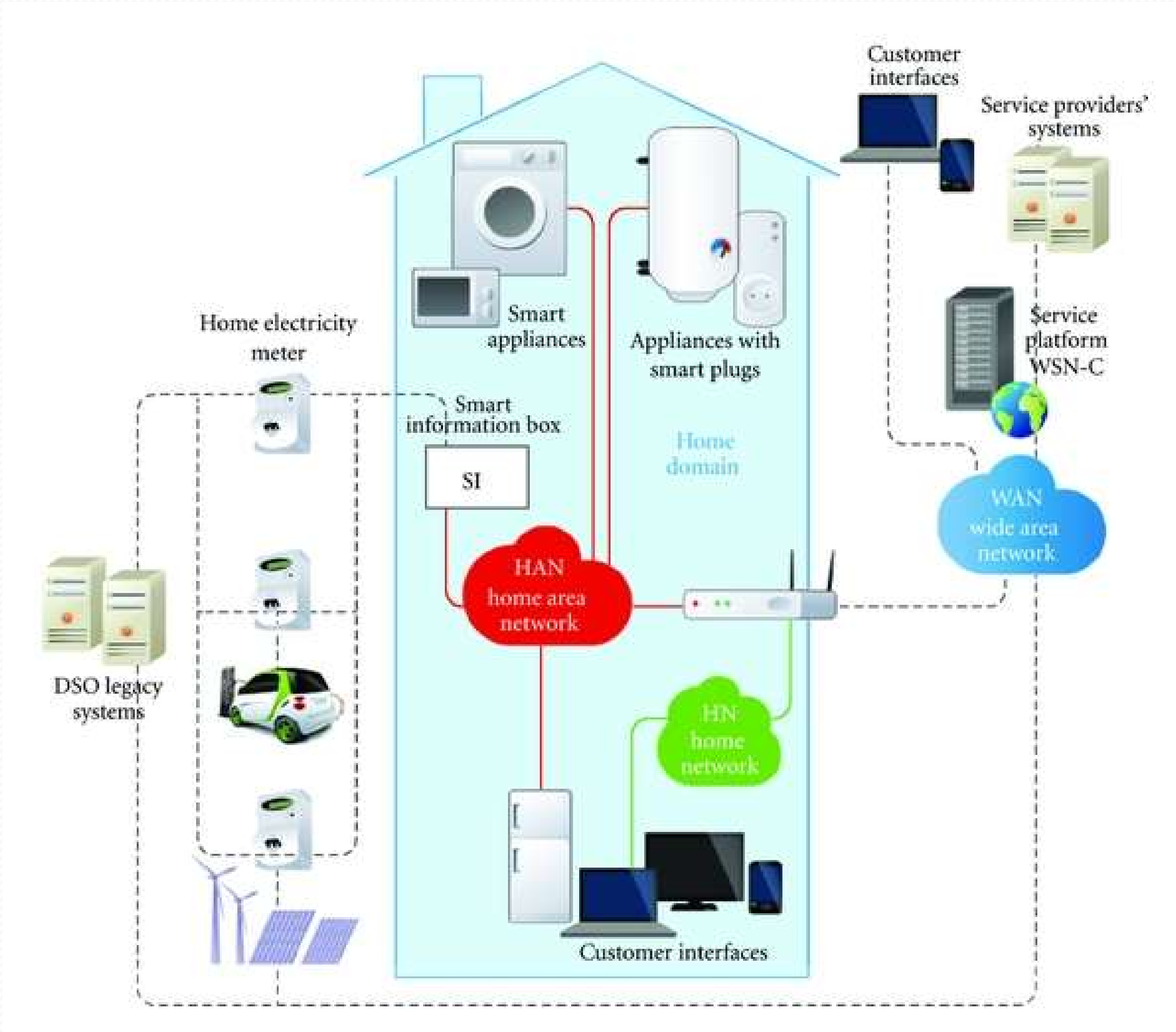
Smart Grid Domains: Distribution

- ✓ Substation automation and distribution automation will be the key enablers for the smart distribution systems.
- ✓ Increasing use of distributed energy resources (DERs) will be an important feature of future distribution systems.
- ✓ Distribution system operator typically controls the distribution system remotely. Communication infrastructure to exchange information between the substations and a central distribution management system (DMS) therefore should be in place.
- ✓ An important job of the distribution system operator is to control the DERs in a coordinated way to ensure stability and power quality of the distribution system.
- ✓ Information exchange between the distribution system operator and the customers for better operation of the distribution system is a new feature of the smart distribution systems.

IoT enabled Smart Distribution System



Home Area Networking (HAN)

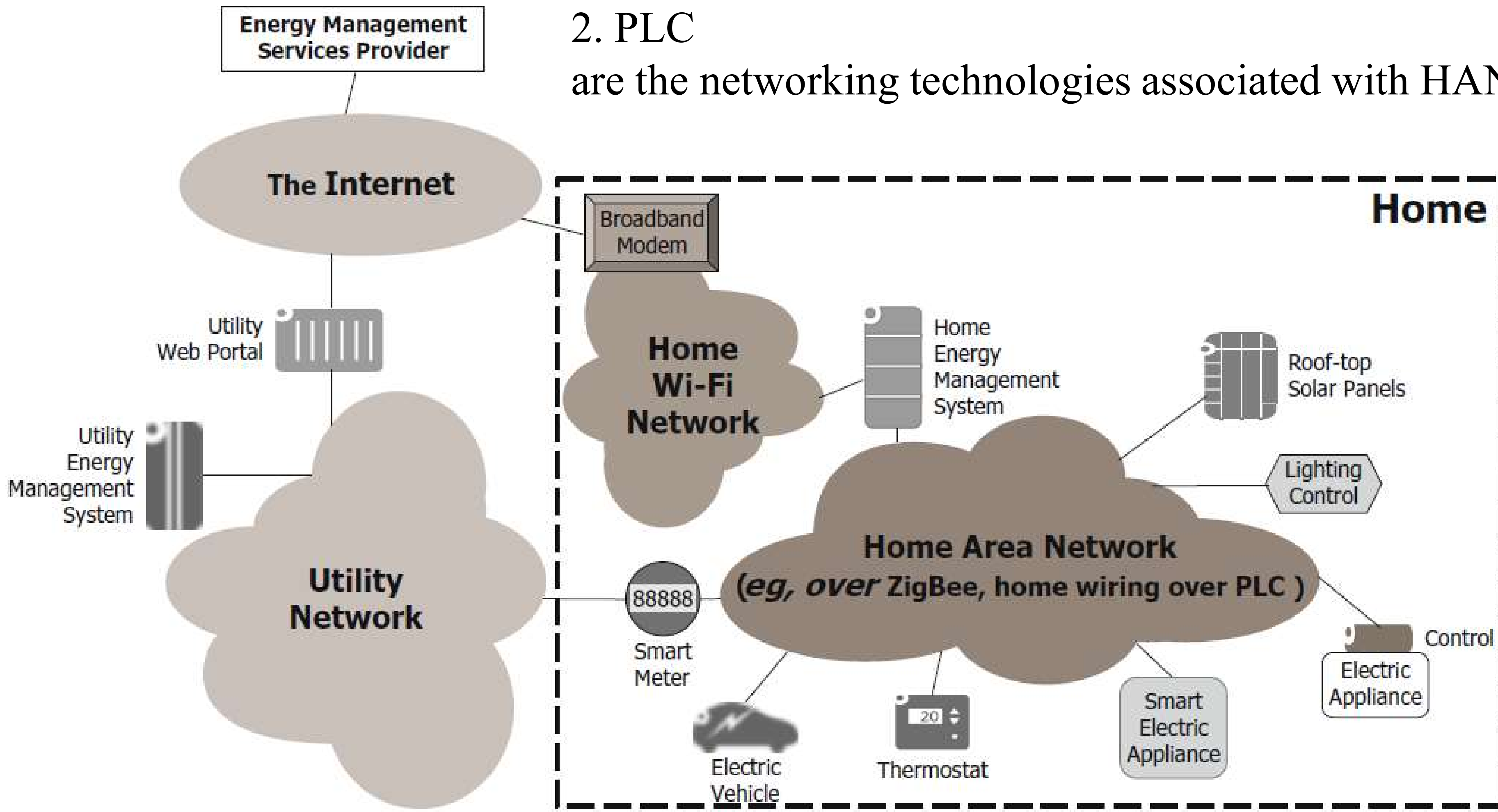


Home Area Networking (HAN)

Home area network schematic

1. Zig Bee standards
2. PLC

are the networking technologies associated with HAN

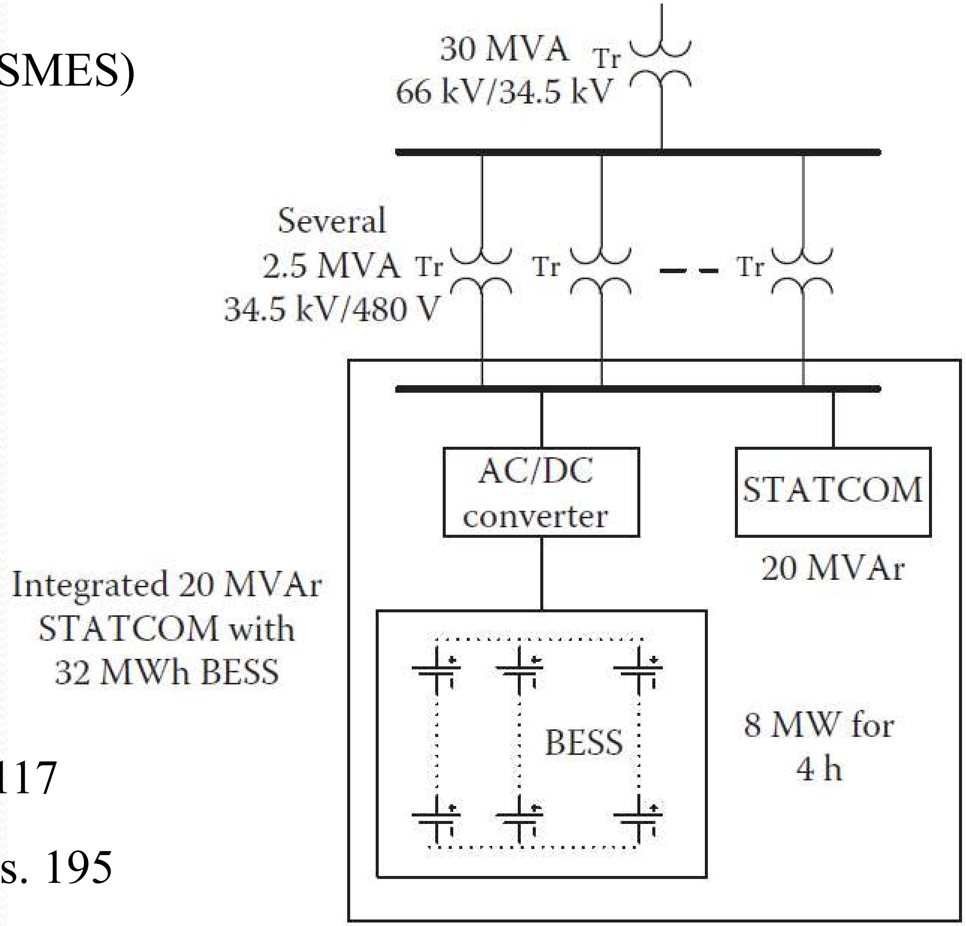


Major Technologies on Energy Storage

1. BES
2. Superconducting magnetic energy storage (SMES)
3. Flywheel energy storage (FES)
4. Compressed air energy storage (CAES)
5. Ultra capacitors
6. Pumped hydro

Capital Costs per Watts

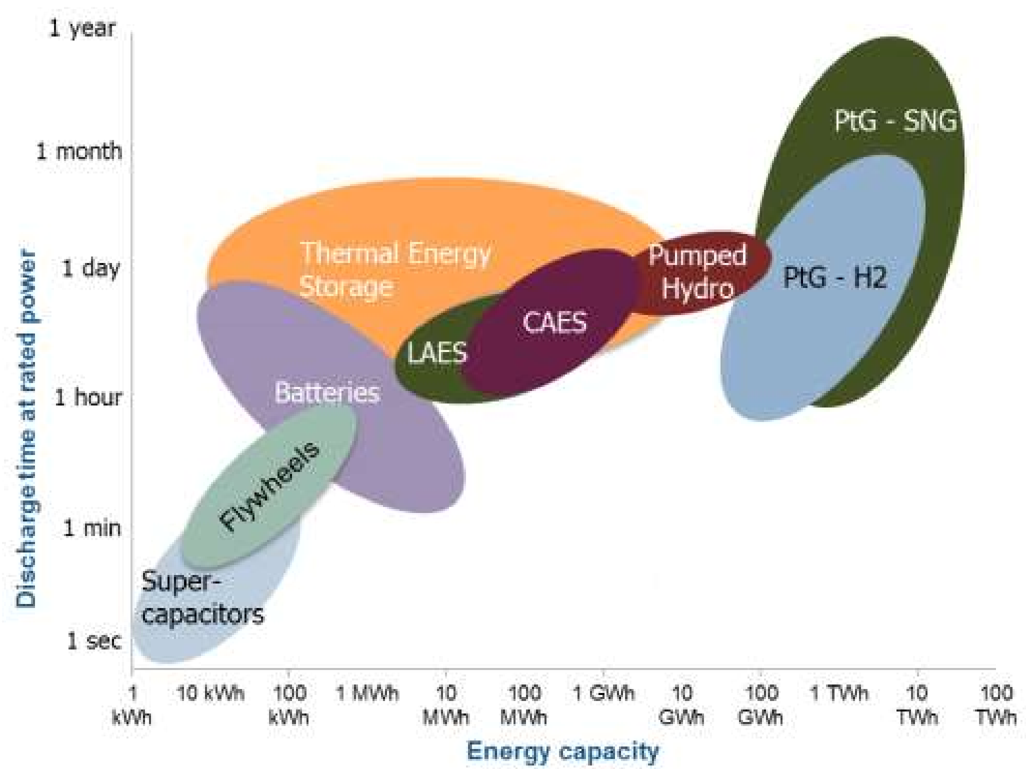
- ✓ Lead Acid – \$1.50 - \$2.00 – Rs. 130
- ✓ Flow Batteries – \$3.00 - \$4.00 – Rs. 260
- ✓ Lithium Ion Batteries – \$1.00 - \$1.80 – Rs. 117
- ✓ Sodium Sulphur Battery – \$2.50 - \$3.00 – Rs. 195
- ✓ Pumped Hydro Storage – \$1.05 - \$4.00 – Rs. 260
- ✓ Compressed Air Storage – \$0.80 - \$9.00 – Rs. 585
- ✓ Molten Salt Storage – \$2.50 - \$5.20 – Rs. 338



Basic Schematic of STATCOM-BESS application

Mapping Storage Technologies According to Performance Characteristics

Storage Technologies	Main Advantages (Relative)	Disadvantages (Relative)
Pumped storage	High capacity, low cost	Special site requirement
CAES	High capacity, low cost	Special site requirement, need gas fuel
Flow batteries: PSB VRB ZnBr	High capacity, independent power and energy ratings	Low energy density
Metal-air	Very high energy density	Electric charging is difficult
NaS	High power and energy densities, high efficiency	Production cost, safety concerns (addressed in design)
Li-ion	High power and energy densities, high efficiency	High production cost, requires special charging circuit
Ni-Cd	High power and energy densities, efficiency	
Other advanced batteries	High power and energy densities, high efficiency	High production cost
Lead-acid	Low capital cost	Limited cycle life when deeply discharged
Flywheels	High power	Low energy density
SMES, DSMES	High power	Low energy density, high production cost
E.C. Capacitors	Long cycle life, high efficiency	Low energy density

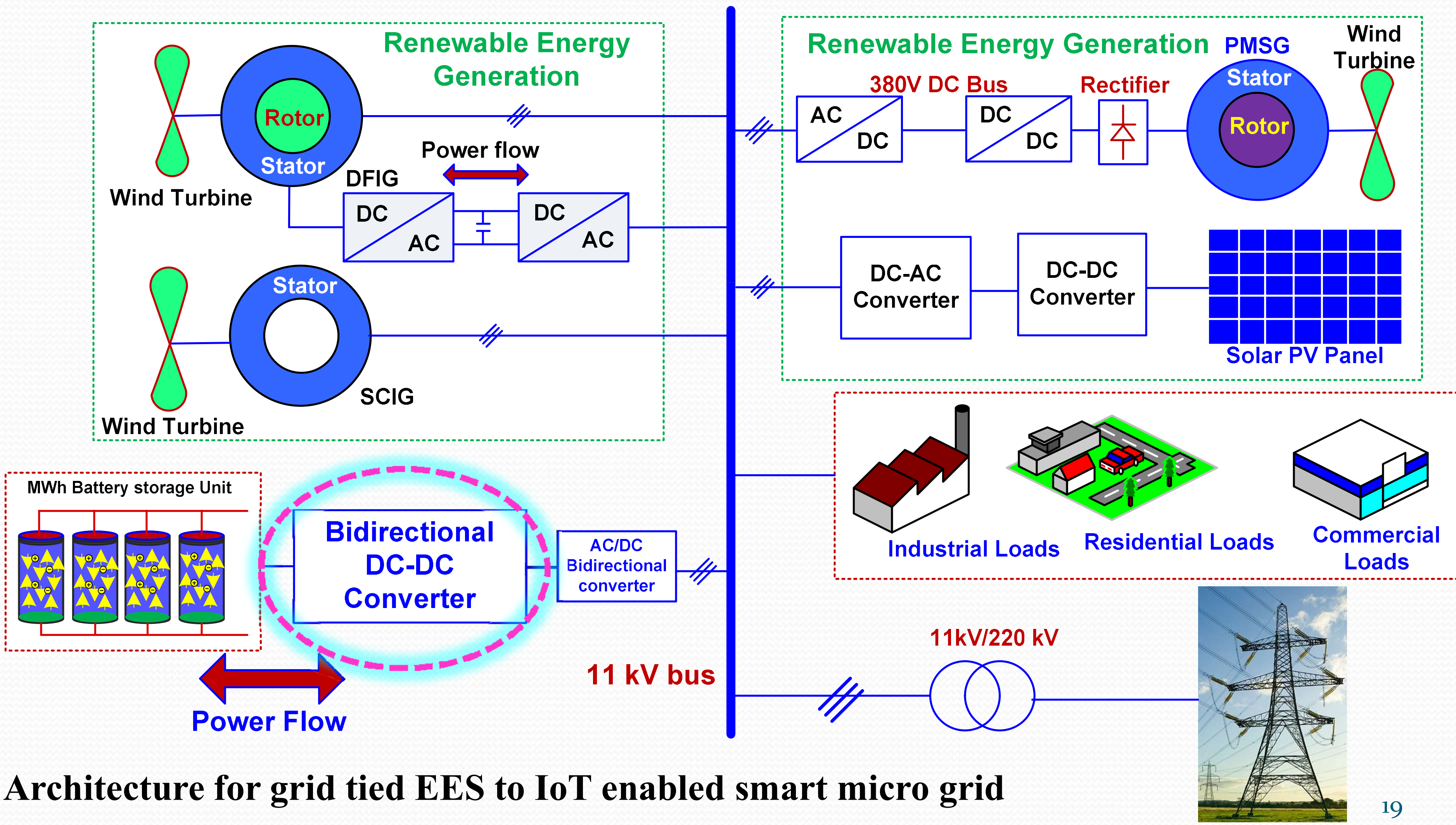


Global Energy Storage to 'Double 6 Times' by 2030

- ✓ The energy storage industry is set to rise dramatically -- for those companies that can play the long game.
- ✓ Forecasts the global energy storage market will "double six times" from now to 2030.
- ✓ The trajectory for energy storage mirrors the market expansion that solar went through from 2000 to 2015, when the share of solar PV as a percentage of total generation doubled seven times.
- ✓ The International Energy Agency's 2017 Energy Outlook released this week doesn't delve into energy storage as deeply as it does renewables, which it projects will capture two-thirds of global investment and provide 40 % of the world's electricity by 2040. But it does note that, since 2010, costs of new solar PV have come down by 70 %, wind by 25 % and battery costs by 40 %.

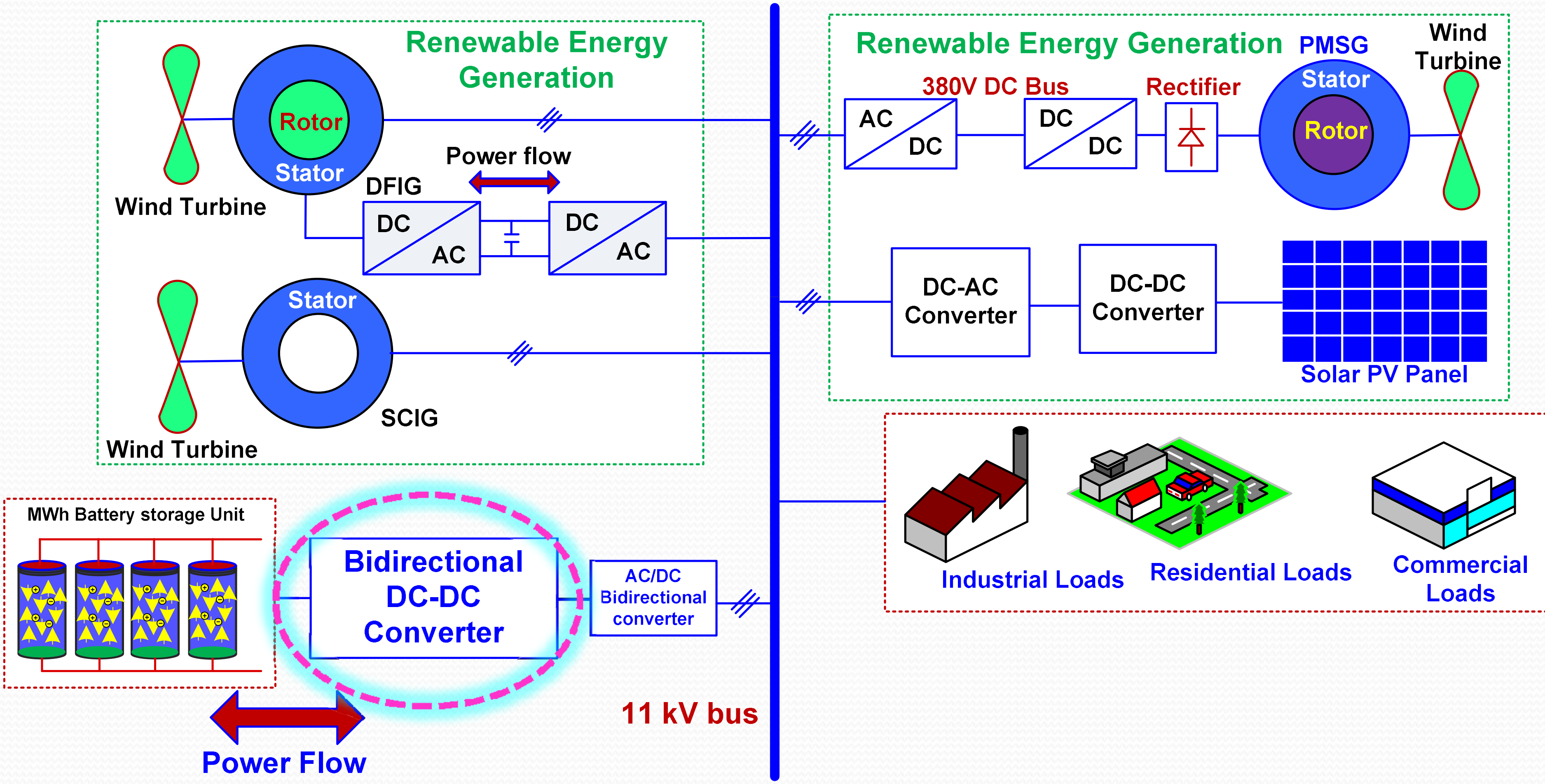
Sumitomo Electric, Yokohama Works, 1MW-5MWh, this application provides for demand side management, renewable Integration and renewable firming.

Role of IoT to EES in Smart Grid : Grid tied



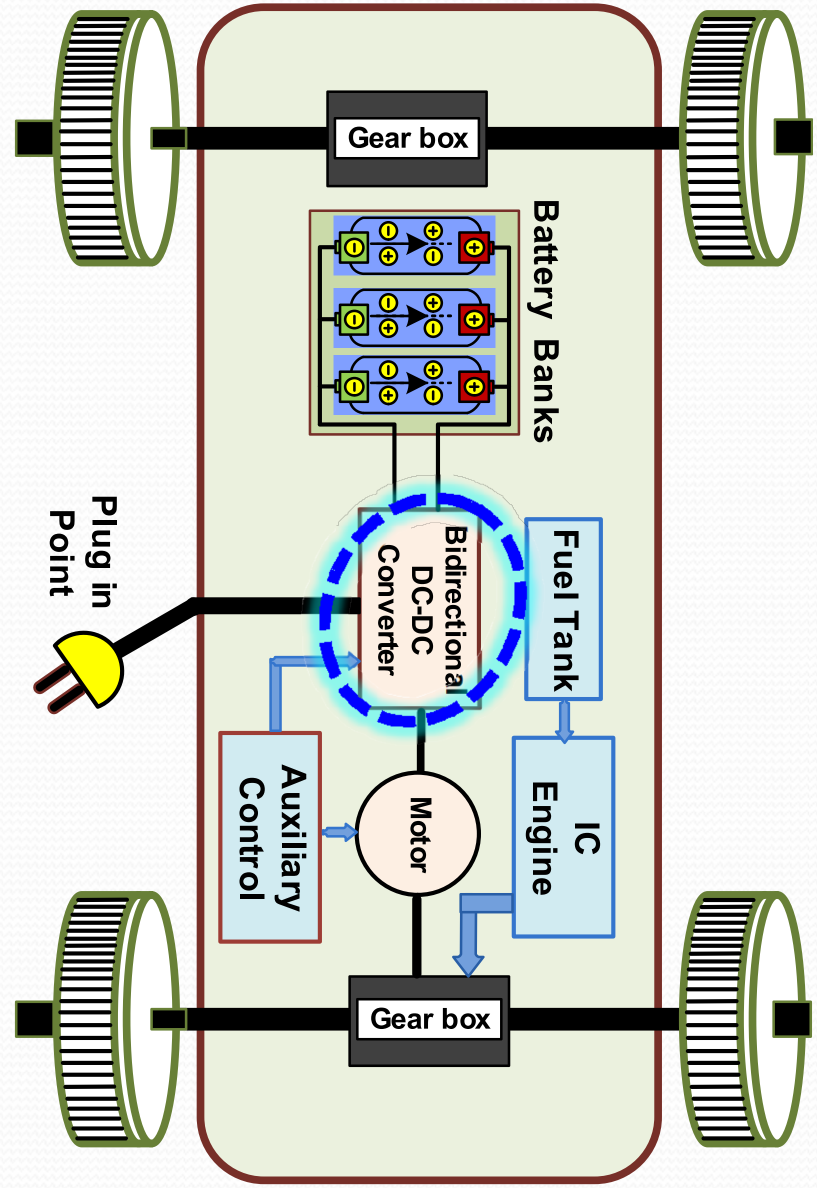
Architecture for grid tied EES to IoT enabled smart micro grid

Role of IoT to EES in Smart Grid : off-grid

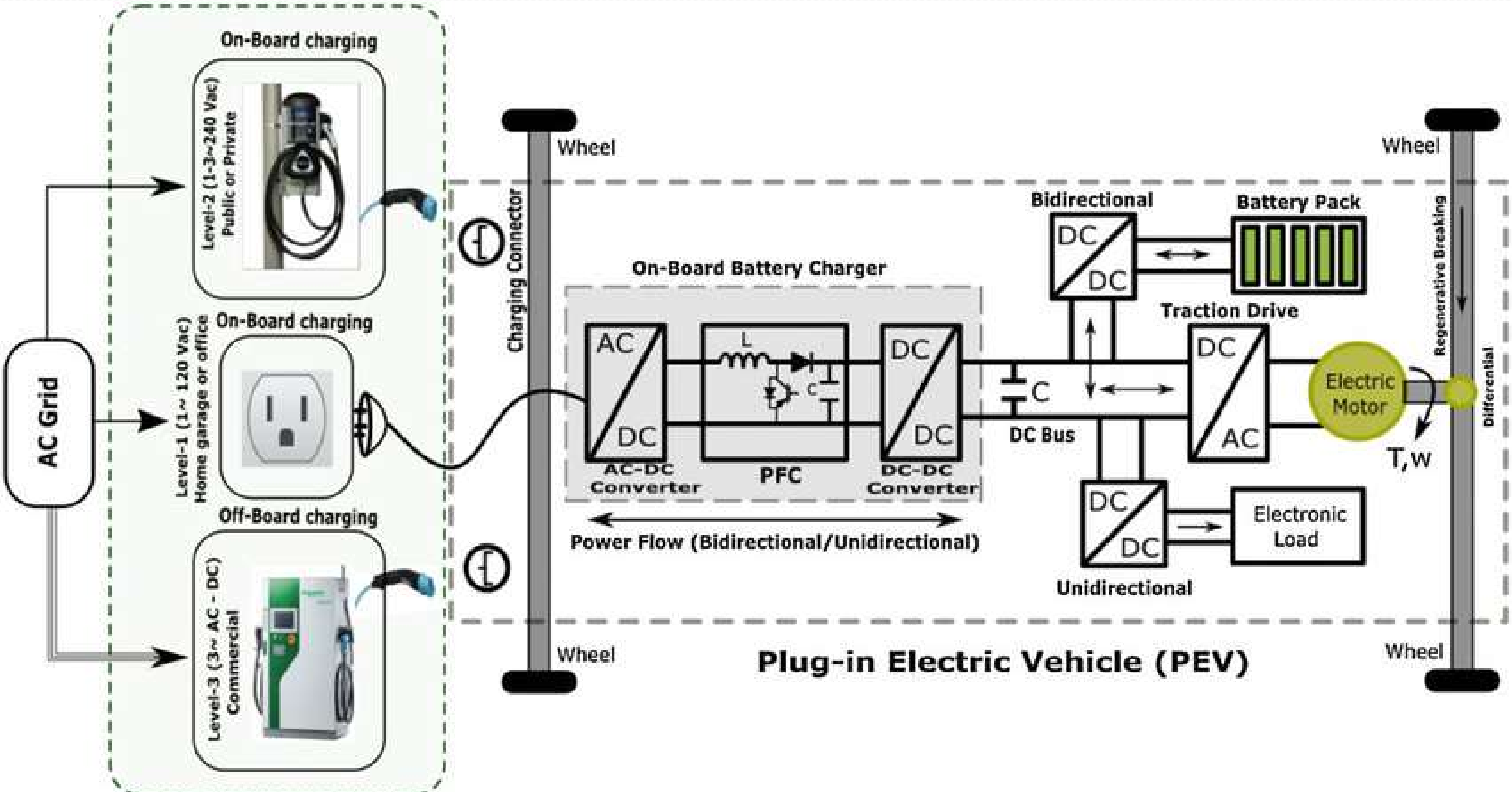


Architecture for off-grid EES to IoT enabled smart micro grid

Role of IoT to EV charger



Role of IoT to EV charger



IoT enabled Smart Grid Technology

Functionalities and Capabilities	Description
Infrastructure: **1. Communication and security**	Underlying communications to support real-time operational and nonoperational smart technology performance
2. Embedded EVs, large-scale renewable generation, DERs	✓ "passive" (local/limited automation, monitoring, and control) system to actively (global/integrated, self-monitoring, semi automated) responds to the various dynamics of the electric grid. ✓ Integration of large-scale renewable energy resources presents a challenge with dispatch ability and controllability of these resources. ✓ Energy storage systems can offer a substantial contribution to alleviate such potential problems by decoupling the production and delivery of energy.
Metering **1. Remote consumer price signals**	Function that provides TOU pricing information

IoT enabled Smart Grid Technology

Functionalities and Capabilities	Description
2. Granular energy consumption data/ Information.	Function with the ability to collect, store, and report customer energy consumption data/information for any required time intervals or near real-time.
3. Identify outage location, extent remotely	Metering function capable of sending signal when meter goes out and identifying themselves after power restoration
4. Remote connection, disconnection	Function capable of remotely controlling “on” and “off” smart asset.
5. Remote configuration	Function capable of being remotely configured for functionality changes and firmware and software updates
6. Optimize retailer cash flow	Ability for a retail energy service provider to manage its revenues through more effective cash collection and debt management

IoT enabled Smart Grid Technology

Functionalities and Capabilities	Description
Grid: **1. Embedded sensing, automation, protection, and control**	1. Wide area system monitoring and advanced system analytics: a real-time, PMU-based grid monitoring system combined with advanced analytics consisting of intelligent fault and outage detection. ✓ PMU-based state estimation enabling real-time dynamic and static system stability analysis, ✓ risk and margin evaluation, ✓ power system optimization, ✓ special protection schemes arming, etc., therefore predict possible severe grid disturbances leading to major power system outages and blackouts. Wide area adaptive protection, control, and automation includes, mitigate wide area disturbances, improve power system transmission capacity, Improve power system reliability, change of operational criteria

IoT enabled Smart Grid Technology

Functionalities and Capabilities	Description
2. Advanced system operation	Advanced system operation tools are comprised of dynamic security assessment and wide area monitoring system (WAMS) and control capabilities.
3. Advanced system management	✓ Advanced asset management enables two-key smart grid capabilities: ✓ Optimum equipment performance leading to effective asset utilization. ✓ This can be accomplished by implementing real-time, dynamic rating applications at grid level. ✓ This allows for planed transfer capabilities and grid assets above the manufacturer's "nameplate" ratings.
Intentional islanding (microgrids) and aggregated load and generation management (VPP)	✓ Intentional islanding and/or grid-parallel operation of electric subsystem. ✓ Allows for optimum, multiple load/generation balancing to enable reliable and cost-effective operation

IoT enabled Smart Grid Technology

Functionalities and Capabilities	Description
***Home/building* Aggregated DR**	Aggregation of demand to reduce peak load and help balance the system more efficiently.
EMS	Ability to control in-home appliances, distributed generation, and EVs to provide an optimum energy consumption

Outcome of IoE in Smart Grid

- ✓ The smart grid has been able to provide better power management technologies through its integrated systems, providing with a better user interface.
- ✓ It has also provided with a protective management system in case of emergency crisis or setbacks.
- ✓ It has been in understanding that smart grids provide with a better supply and demand management.
- ✓ The smart grid has not only provided with a longer battery timing but also with better power quality to its consumers.
- ✓ Previous grid stations used to emit a large amount of carbon dioxide which in this case has been terminated at all.
- ✓ It has also provided with the convenience of reading meters remotely. Meter readers will not have to physically appear at the property and check for meter readings. It will all be done through IT resources.

Outcome of IoE in Smart Grid

Benefits to Utility	Benefits to Consumer
➢ Reduction in losses ➢ Increased Grid stability ➢ Peak load management ➢ Renewable integration ➢ Self-healing grid ➢ Reduced Capital & operational cost ➢ Increased employee safety ➢ Higher customer satisfaction ➢ Opportunities to leverage its resources and enter new markets ➢ Increased asset utilization	➢ Prosumers (Producer & Consumer) enablement ➢ Improved quality of power supply ➢ User friendly & transparent interface with utilities ➢ Reduction in electricity bills by shifting loads from peak hours to non-peak hours ➢ Opportunity to interact with the electricity markets through home area network and smart meter connectivity ➢ Opportunity to purchase energy from clean resources, further creating a demand for the shift from a carbon-based to a "green economy"

Difference b/w Traditional and IoE enabled Smart Grid

Characteristics	Traditional Grid	IoE enabled Smart Grid
Technology	**Electromechanical:** ✓ Electromechanical. ✓ A mechanical device that is electrically operated. ✓ Technology is “dumb” Absence of communication between devices and little internal regulation.	**Digital:** The smart grid employs digital technology allowing for increased communication between devices and facilitating remote control and self-regulation
Distribution	**One-Way Distribution:** Power can only be distributed from the main plant using traditional energy infrastructure.	**Two-Way Distribution:** ✓ While power is still distributed from the primary power plant, in a smart grid system, power can also go back up the lines to the main plant from a secondary provider. ✓ An individual with access to alternative energy sources, such as solar panels, can actually put energy back on to the grid.

Difference b/w Traditional and Smart Grid

Characteristics	Traditional Grid	IoE enabled Smart Grid
Generation	**Centralized:** With traditional energy infrastructure, all power must be generated from a central location. This eliminates the possibility of easily incorporating alternative energy sources into the grid	**Distributed:** Using smart grid infrastructure, power can be distributed from multiple plants and substations to aid in balancing the load, decrease peak time strains, and limit the number of power outages.
Sensors	**Few Sensors:** The infrastructure is not equipped to handle many sensors on the lines. This makes it difficult to pinpoint the location of a problem and can result in longer downtimes..	**Sensors Throughout:** In a IoE smart grid infrastructure system, there are multiple sensors placed on the lines. This helps to pinpoint the location of a problem and can help reroute power to where it is needed while limiting the areas affected by the downtime.

Difference b/w Traditional and Smart Grid

Characteristics	Traditional Grid	IoE enabled Smart Grid
Monitoring	**Manual:** Due to limitations in traditional infrastructure, energy distribution must be monitored manually.	**Distributed:** The IoE smart grid can monitor itself using digital technology. This allows it to balance the power loads, troubleshoot outages, and manage distribution without the need for direct intervention from a technician.
Restoration	**Manual:** In order to make repairs on traditional energy infrastructure, technicians have to physically go to the location of the failure to make repairs. The need for this can extend the amount of time that outages occur.	**Self-Healing:** Sensors can detect problems on the line and work to do simple troubleshooting and repairs without intervention. For problems related to infrastructure damage, the smart grid can immediately report to technicians at the monitoring center to begin the necessary repairs.

Difference b/w Traditional and Smart Grid

Characteristics	Traditional Grid	IoE enabled Smart Grid
Equipment	**Failure & Blackout:** As a result of aging and limitations, traditional energy infrastructure is prone to failures. Failure of infrastructure can lead to blackouts, a condition where the end customer is receiving no power to their unit causing downtime.	**Adaptive & Islanding:** Using a smart grid system, power can be rerouted to go around any problem areas. This limits the area impacted by power outages and can do it on a per residence level.
Control	**Limited:** Using traditional power infrastructure, energy is very difficult to control. After leaving the power plant or substation, companies have no control over the energy distribution.	**Pervasive:** With the increased amount of sensors and other smart infrastructure, energy companies have more control than power distribution. Energy consumption can be monitored all the way down the line; from the moment it leaves the power plant, all the way to the consumer.

Difference b/w Traditional and Smart Grid

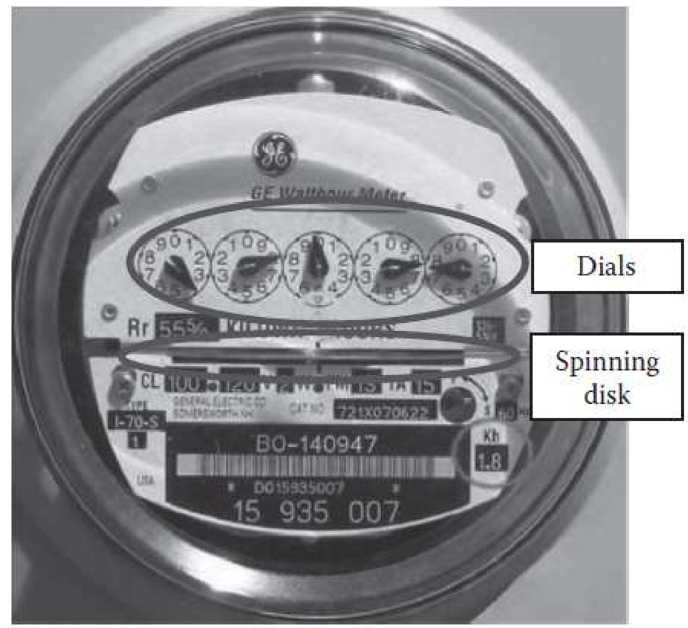
Characteristics	Traditional Grid	IoE enabled Smart Grid
Customer Choices	**Fewer:** The traditional power grid system infrastructure is not properly equipped to give customers a choice in the way they receive their electricity. Alternative energy sources, for example, have to be separated from power plants and traditional grid infrastructure. This is also part of the reasoning behind the establishment of electric companies as a public utility.	**Many:** Using smart technologies, infrastructure can be shared. This allows more companies and forms of alternative energy to come on to the grid allowing consumers to have more choice in how they receive energy.

IoT enabled Smart Meters

Smart Meter:

Smart meters are defined by their functionality. A typical set of smart meter functions is as follows:

- ✓ Two-way communications between the utility and the meter.
- ✓ Recording of usage intervals of 15 or 60 min.
- ✓ Sending of data to the utility at least daily.
- ✓ Internal switch to disconnect the power.
- ✓ HAN interface.
- ✓ Recording of power quality information such as voltage and outages.
- ✓ Functionality to ensure reliable and secure data communications.



Evolution of the Electric Meter

Electric meters fall into two basic categories: Electromechanical and Electronic meter.

IoT enabled Smart Meters

There are several drawbacks to the Electromechanical Meter:

Inefficient: Sending utility employees to walk house to house to manually read each meter and record each customer electricity usage is labour intensive and can be expensive depending on the location of the utility and the country.

Inaccurate: While the meters themselves are prone to inaccuracies, the manual meter reading and manual data entry into the billing system is also a source of error. Any errors required a significant amount of time to resolve, usually involving a separate visit to the customer to read the meter again.

Tamper prone: Tampering with electromechanical meters to reduce the amount of energy registered by the meters can be one of the major sources of energy losses in a utility T&D system. Electromechanical meters are relatively easy to bypass or manipulate to alter energy usage readings.

No remote monitoring or control functionality: As part of the process of dealing with customers moving residences (typically more frequently for apartments or high-turnover housing, such as college campuses) and people not paying their electricity bills, utilities have to send someone out to the customer to turn the power off and back on for new customers. Also, if a customer reported loss of power, the utility would need to send someone to the customer to verify if the power supply on the utility side of the meter had failed or if it was an issue on the customer side of the meter.

IoT enabled Smart Meters

No consumer visibility of energy usage: Unless consumers physically read their own meters on a regular basis and more frequently than the billing cycle, they have no visibility of their energy usage until they receive the bill. Without detailed or real-time information on energy usage and time-based energy pricing, consumers have much less ability to reduce or time-shift energy usage and save money on their bills.

Electronic Meter:

The advent of electronic metering gave way to a more economical manufacturing process over electromechanical meters, mostly due to the electronic content, but also since one electronic meter could handle multiple meter configurations through firmware or software changes compared to the different types of electromechanical meters required for different applications

Electricity Price

Defining Dynamic Pricing: Six Basic Structures for Firm or Default Service

- ✓ Flat energy rates
- ✓ Flat demand/energy rates
- ✓ Tiered rates (inclining or declining blocks)
- ✓ Time of use (TOU) rates
- ✓ Critical-peak pricing (CPP)
- ✓ Variable peak pricing (VPP) rates
- ✓ Real time pricing (RTP) rates

Time of Use (TOU):

- ✓ Prices for peak, shoulder and off-peak periods established a year in advance.

Critical-peak pricing (CPP)

- ✓ CPP is similar to TOU pricing, but instead of having a daily schedule, the CPP is declared only on the few days.

Variable Peak Pricing (VPP):

- ✓ A hybrid of TOU and RTP
- ✓ The on-peak period (hours and seasons) is defined in advance Peak period prices for the next day are established based on the day ahead forecast of wholesale market prices.

Real-time Pricing (RTP) :

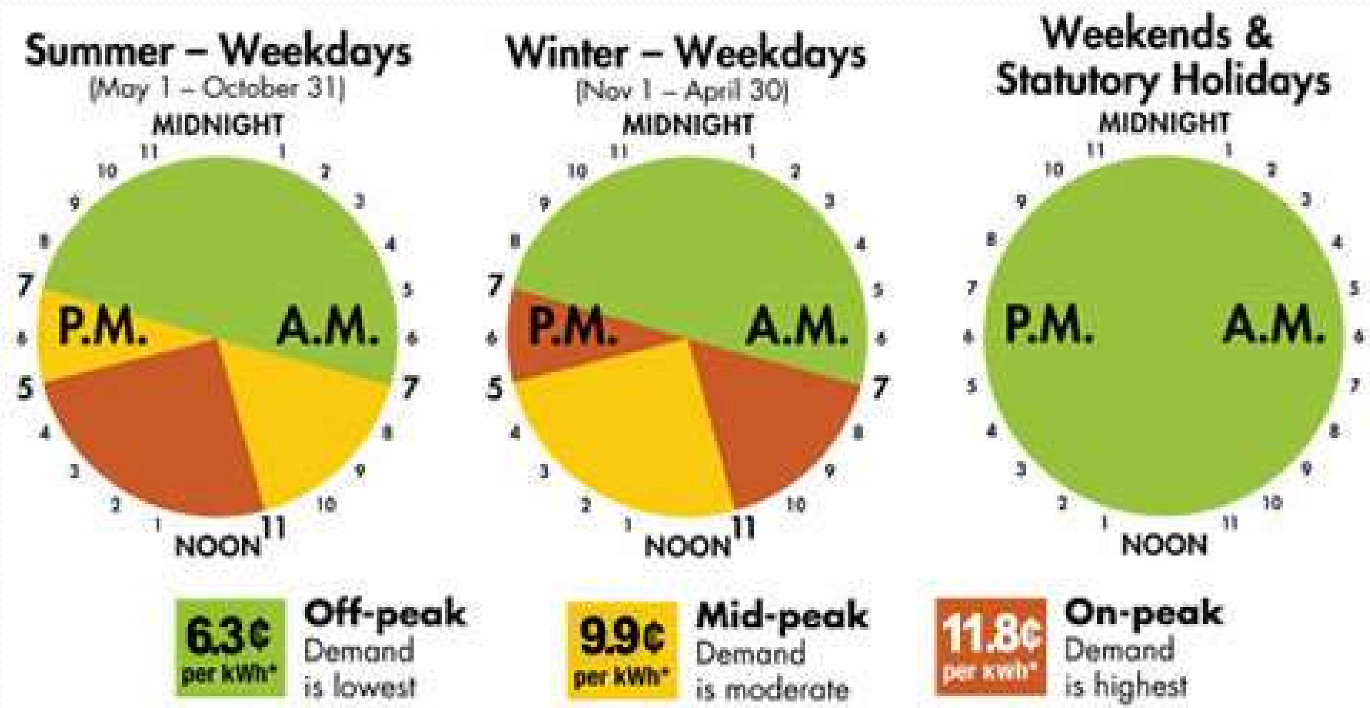
- ✓ Hourly prices change based on system or market conditions on a day ahead, hour-ahead or real-time basis.

IoT enabled Time-of-Use Energy

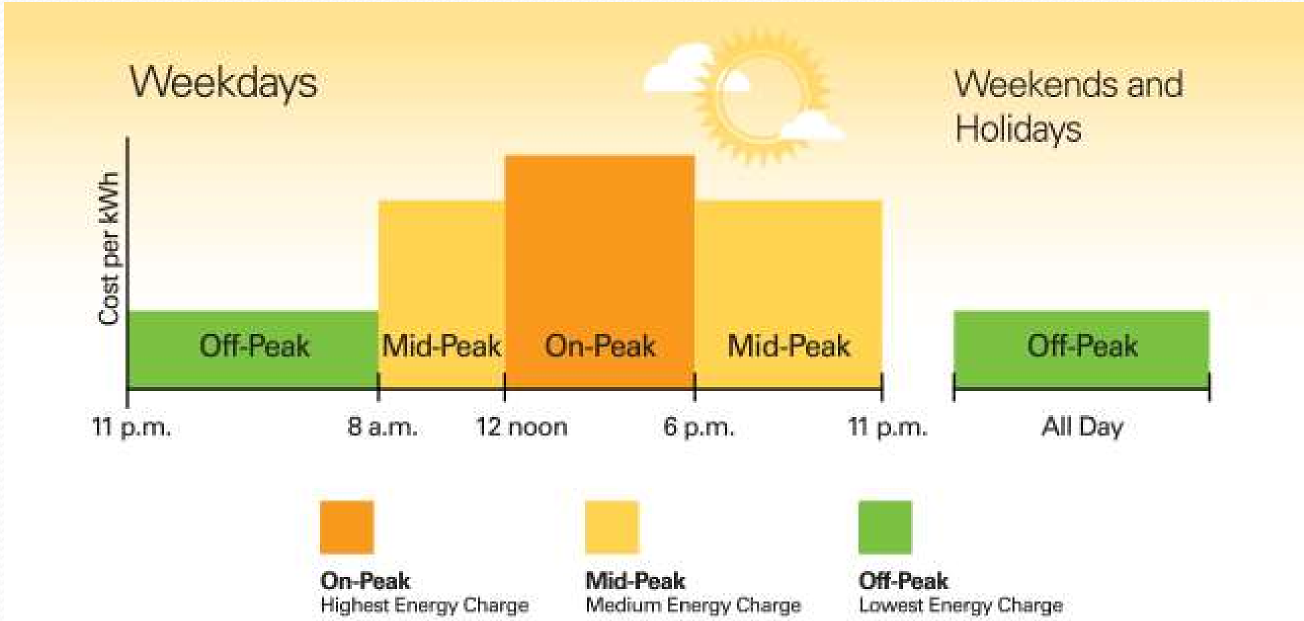
- ✓ We need a smart meter to be eligible to participate in a TOU program.
- ✓ Traditionally, consumers are charged a flat rate for their electricity consumption during a predetermined time period (e.g. 8 a.m. to 10 a.m.).
- ✓ This flat rate is determined by taking into account higher-priced on-peak and lower-priced off-peak rates.
- ✓ With TOU pricing, energy consumers pay the actual lower rates for off-peak usage and higher rates for on-peak usage.

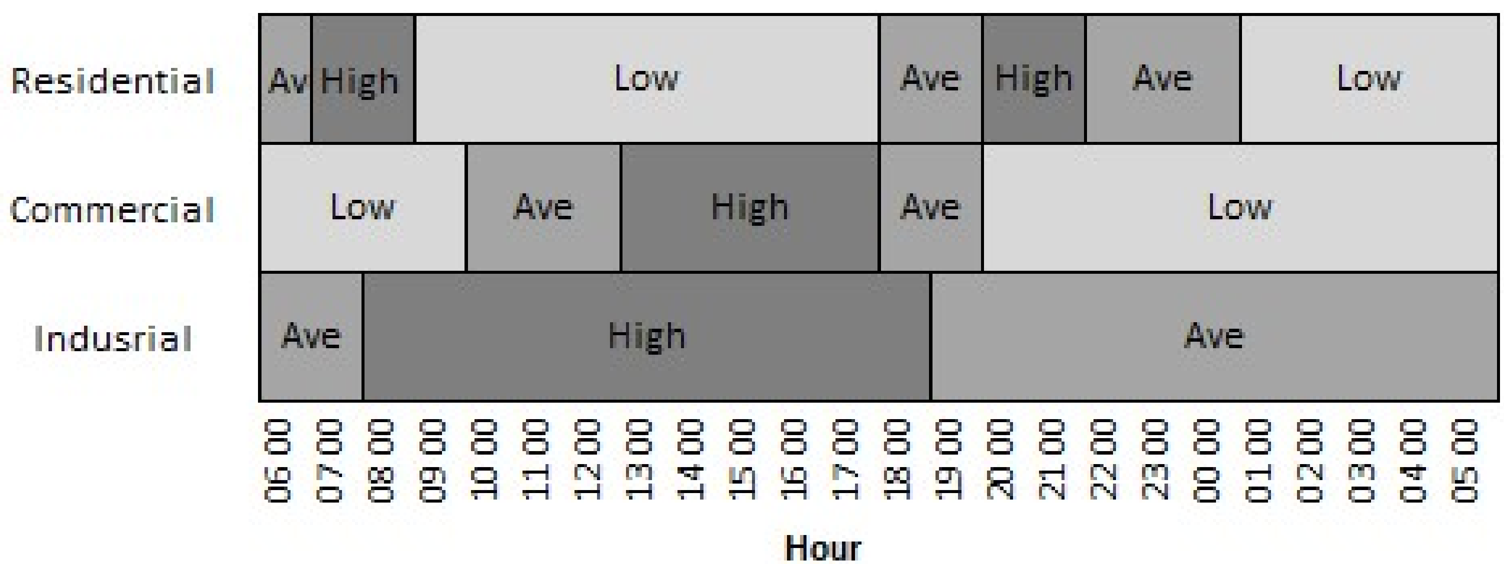
Time of use (TOU):

- ✓ TOU rates have existed in some countries for many decades because they are simple to implement.
- ✓ The peak-time schedule is typically determined seasonally, and it sometimes has a "shoulder" rate that is an intermediate rate between the off-peak and on peak rates.



Time of use (TOU):



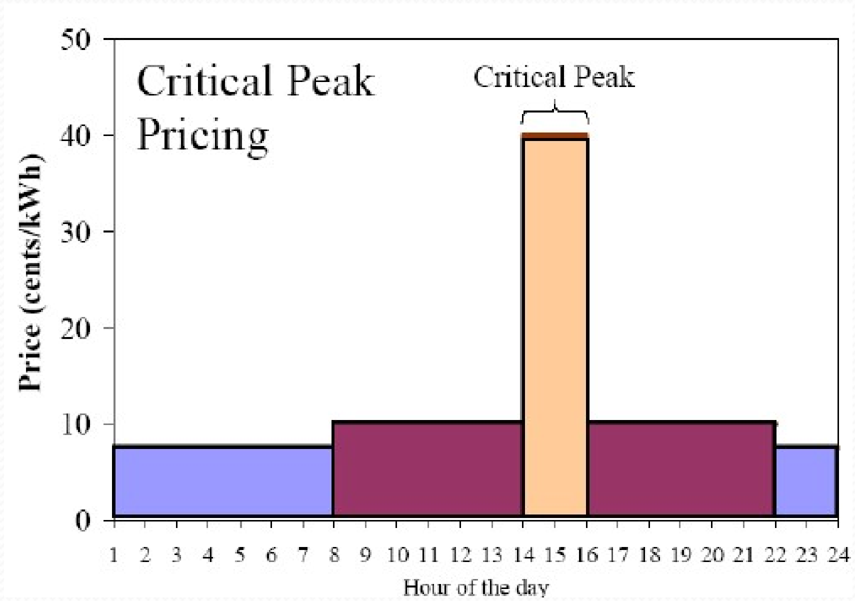


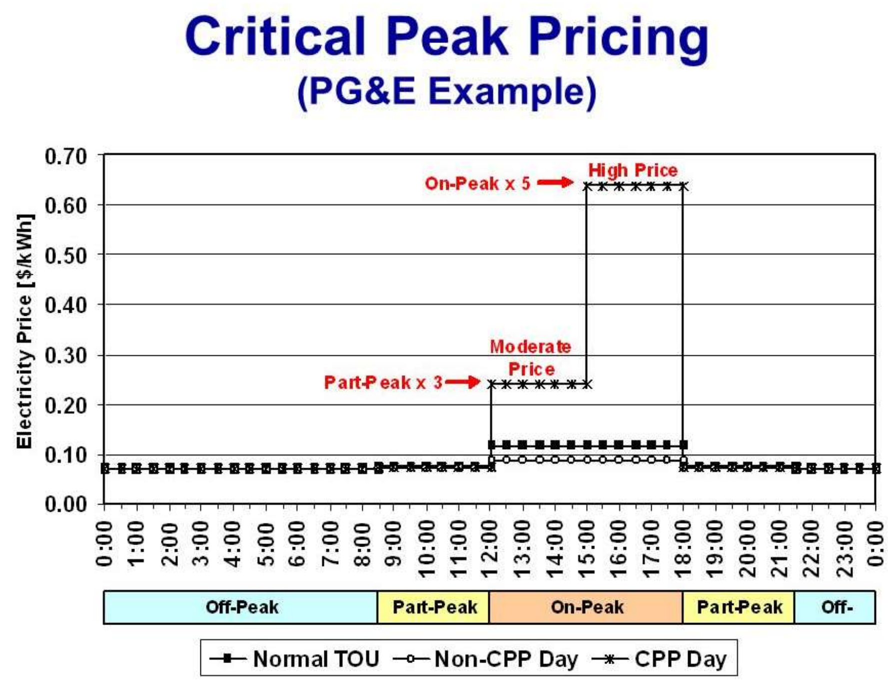
Critical-peak pricing (CPP):

Critical-peak pricing (CPP):

- ✓ CPP is similar to TOU pricing, but instead of having a daily schedule, the CPP is declared only on the few days the utility expects peak conditions to prevail.

- ✓ For this reason, the price on critical peak is usually very much higher than the standard rate. It is not unusual to find the CPP rate is more t





Real-Time Pricing (RTP):

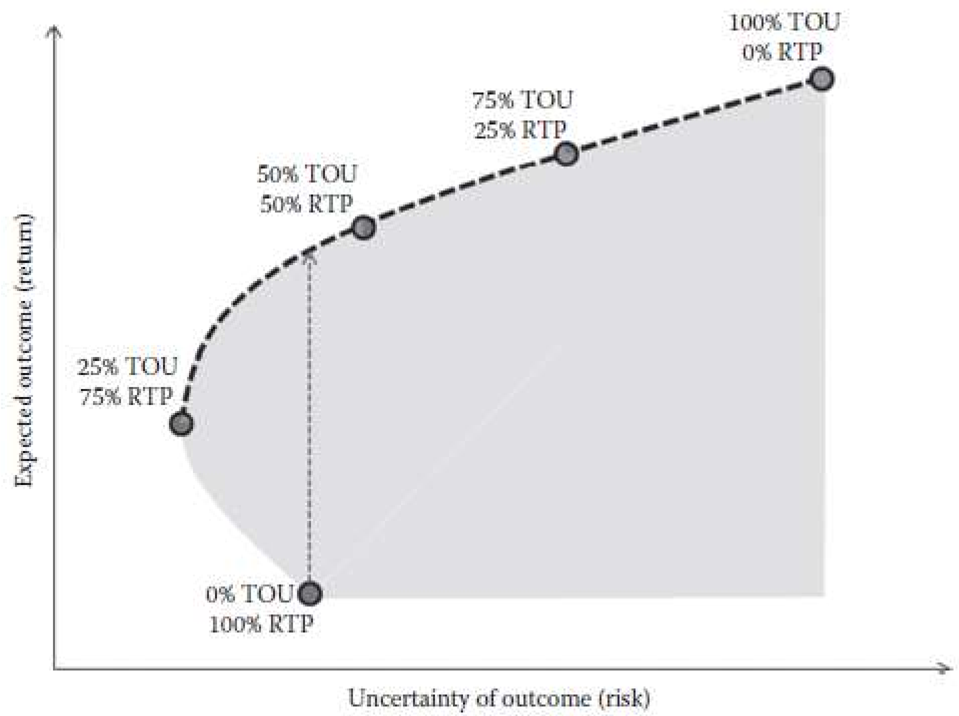
Dynamic pricing (DP) or Real-time pricing (RTP):

- ✓ DP or RTP works by sending customer prices that reflect to some extent the variations in prices seen at the wholesale level. Unfortunately, because the fluctuations in wholesale prices can be unpredictable and vary as frequently as every min, RTP can be difficult for customers to respond to without special hardware. RTP is a closed loop price-based DR control strategy.
- ✓ The implementation of RTP can be difficult to understand, but its flexibility and scalability are very important attributes that have led to growing interest in its use.
- ✓ RTP systems may require DR equipment to be installed in the customers' homes. The fact that prices change in periods as short as 5 min means that customer cannot be expected to respond all the time.
- ✓ Some may contend that customers will not accept price change more frequently than hourly. For this reason, RTP systems include devices that can respond to prices and interact automatically on behalf of the customer.
- ✓ One very important caveat for RTP in particular is that a customer's subscription must be voluntary.

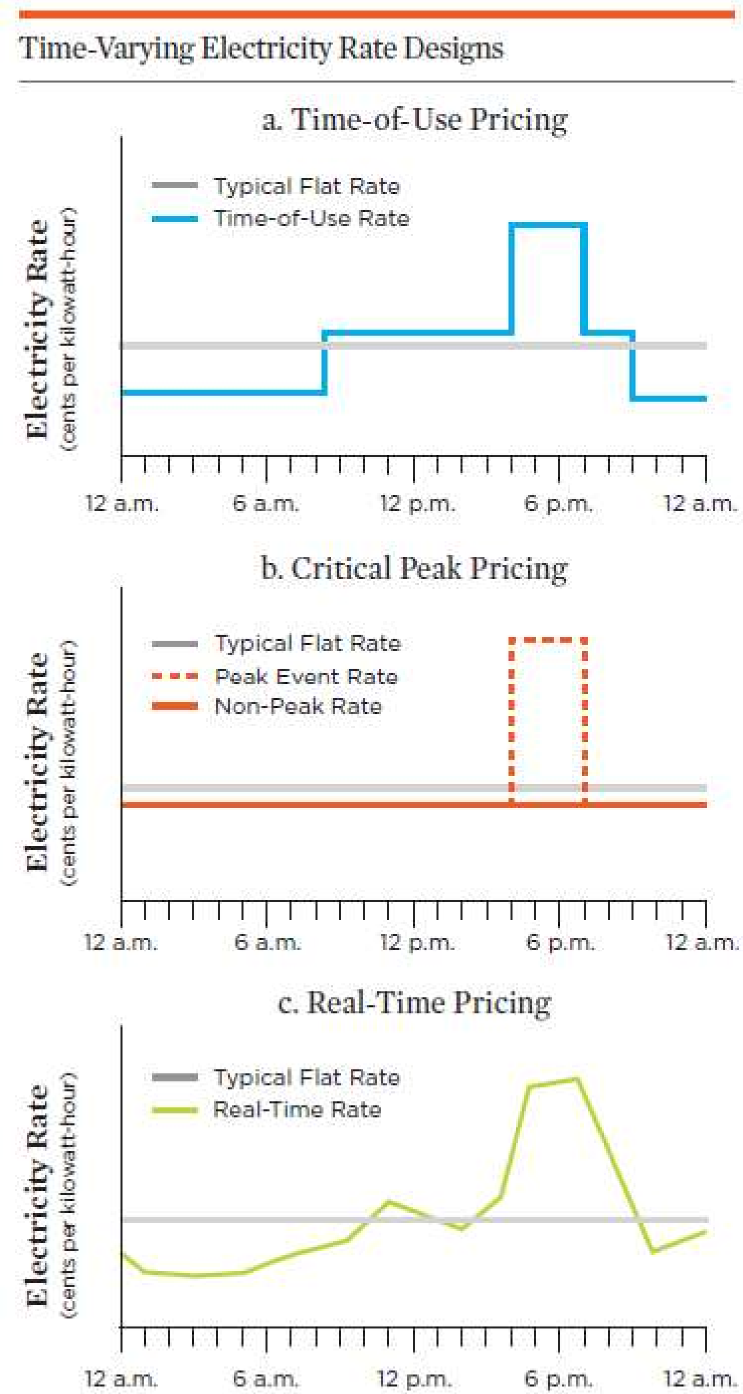
i. More active involvement on the utility's part in helping customers understand what they can do to reduce their usage.

ii. More active involvement on the customers' part in what they use and when they use it.

Summary of All Pricing



A utility proposed to place all its customers on the RTP rate and none of the TOU rate. The expected earnings would be low, but the uncertainty would also be quite low. However, for the same uncertainty, the utility could realize significantly higher expected earnings by choosing a more balanced mixture of customers on each rate. Thus, for any outcome the utility wishes to maximize, only the mixtures of rates that lie on the top of the curve would be efficient, and all other mixtures would be suboptimal.




Thank you