Lecture 1: Introduction to Smart Energy Management Systems (EMS)

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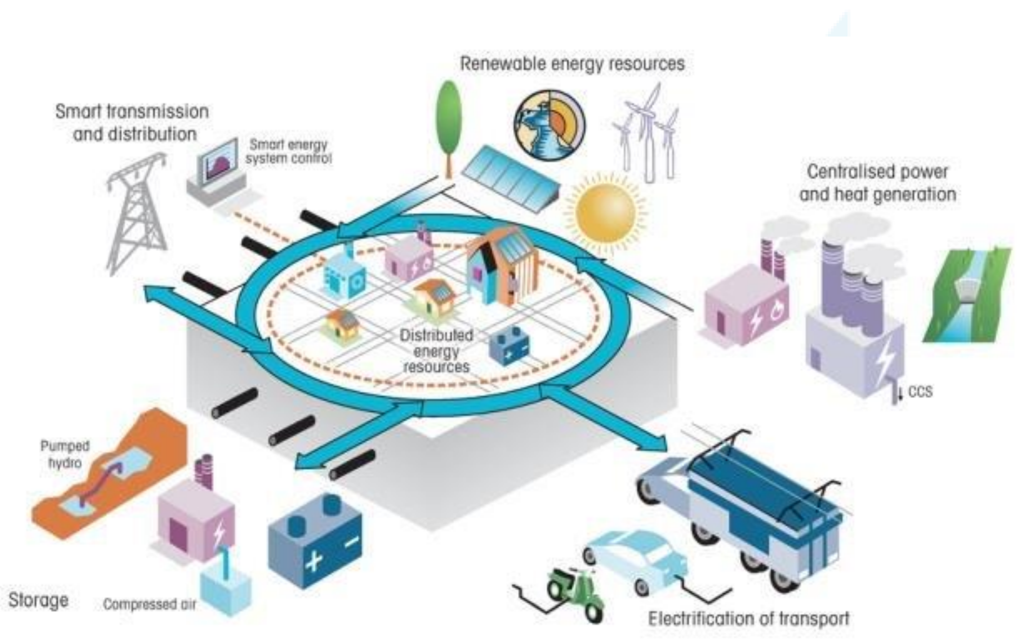
Content of the lecture

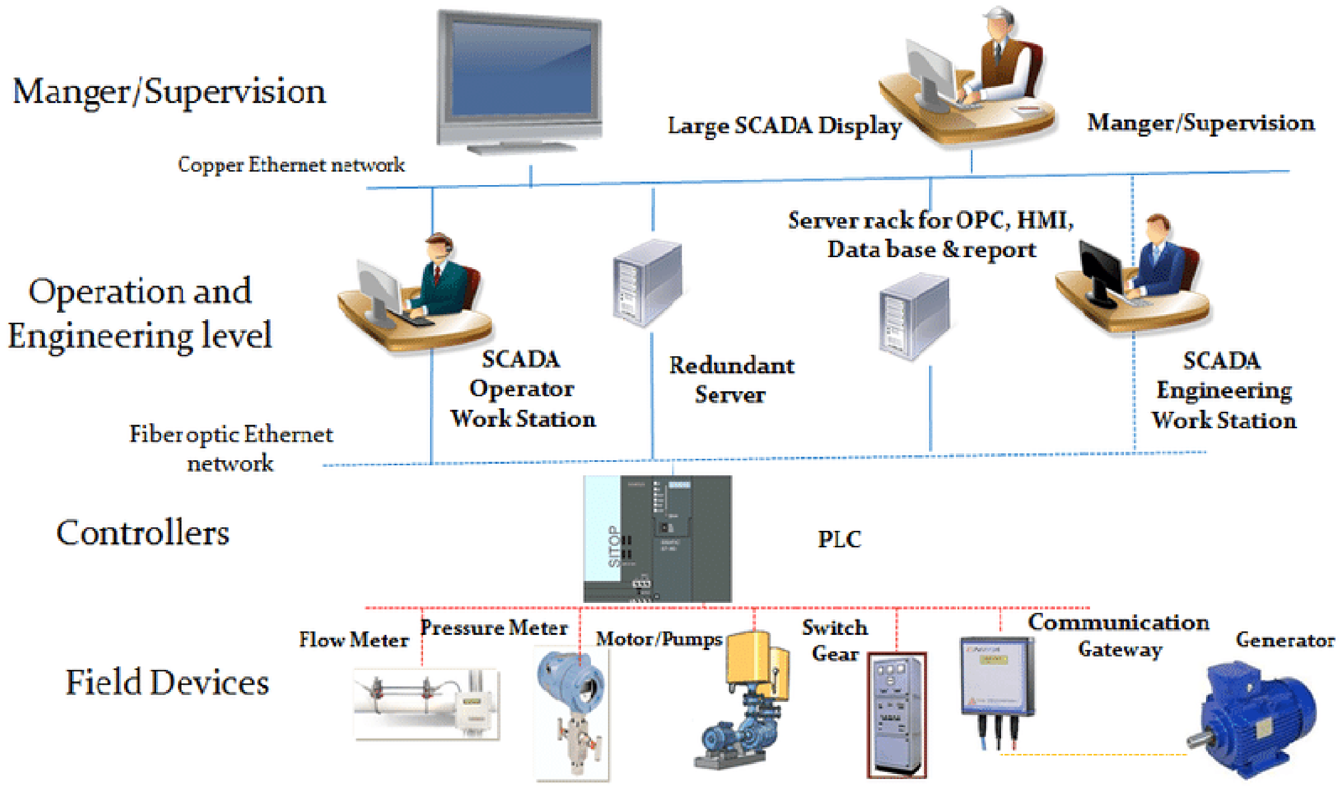
1.1 Objectives and outcomes of this module

- The main objective of the module "Smart Energy Management Systems" is to present the evolution –and state of the art- of Smart power Grids and their corresponding energy management systems so that students become familiar with this revolutionary field.
- Students will learn about the modern "Smart Grid" technologies and its functional components, i.e. the Smart Energy Management systems (Smart Meters, Demand prediction, energy supply control, interoperability, Cyber security and communication, PV system design and installation etc.). They will also get a flavor of design techniques for Smart energy systems.



1.1 Objectives and outcomes of this module

- In addition, terms such as power systems, SCADA (Supervisory control and Data acquisition), EMS (Energy Management Systems), Internet of Things, Cyber security and load forecasting will be explained through examples and exercises.
- In the end, it is expected that students will understand the basics of Smart Grid design and Smart Energy management Systems and will be able to provide solutions to emerging problems, as well as to optimize the current Smart Grid functioning technology.



1.2 Smart Energy Management Systems

Smart functions (including demand prediction, optimization control and BCP support) nowadays interface with conventional energy management functions to realize energy **savings** and **stable** supply of electric power and thermal energy.

Conventional EMS functions

- Monitoring and control functions
  - Electric power monitoring and control functions
  - Air conditioning monitoring and control functions
  - Trend functions
  - Ledger functions
- Visualization functions
  - Energy analysis functions
  - Energy consumption Monitoring functions
  - Energy conservation evaluation report preparation functions
  - Facility ledger management functions

+

Additional smart functions

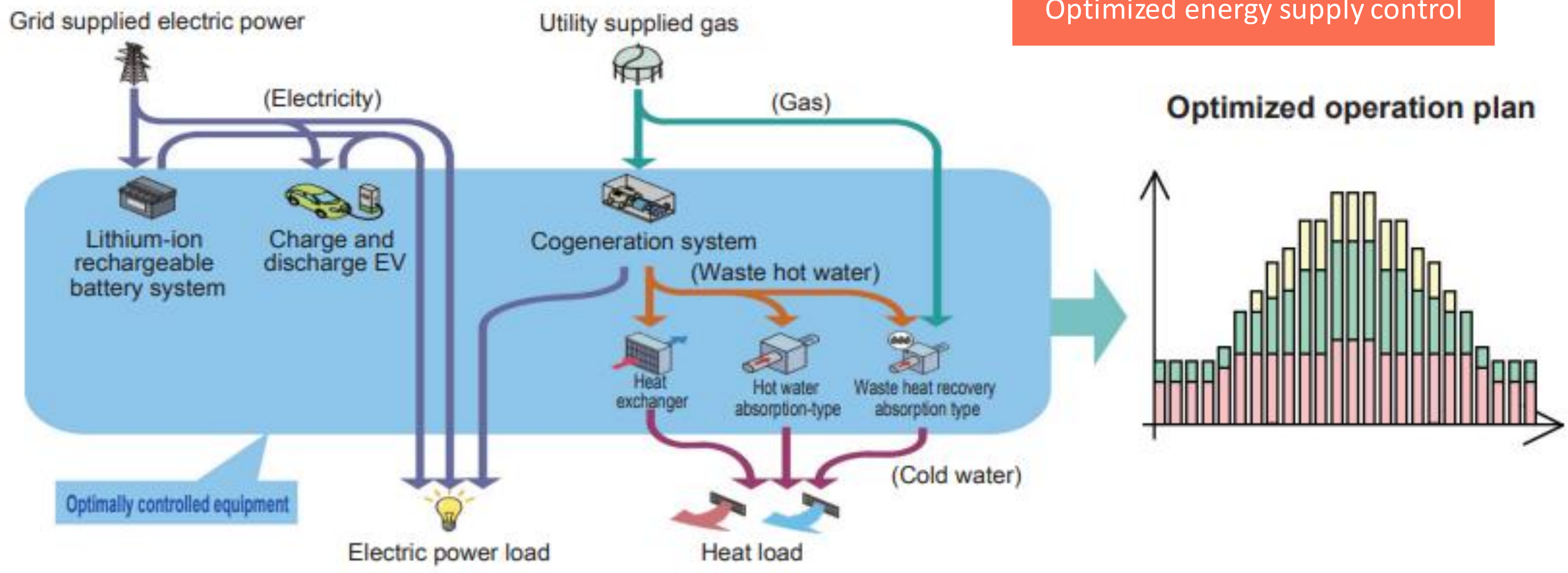
- Smart functions
  - Demand prediction functions
  - Energy supply optimized control functions
  - Electric vehicle (EV) optimized charging and discharging functions
  - Inter-building cooperative functions
  - Local community cooperative functions
- BCP responsive functions
  - Electric power consumption limiting functions
  - On premises electric power operational support functions
  - Scheduled power outage responsive functions

= Energy conservation + Stable supply

* BCP = Business Continuity Plan

1.2 Smart Energy Management Systems

Optimized energy supply control



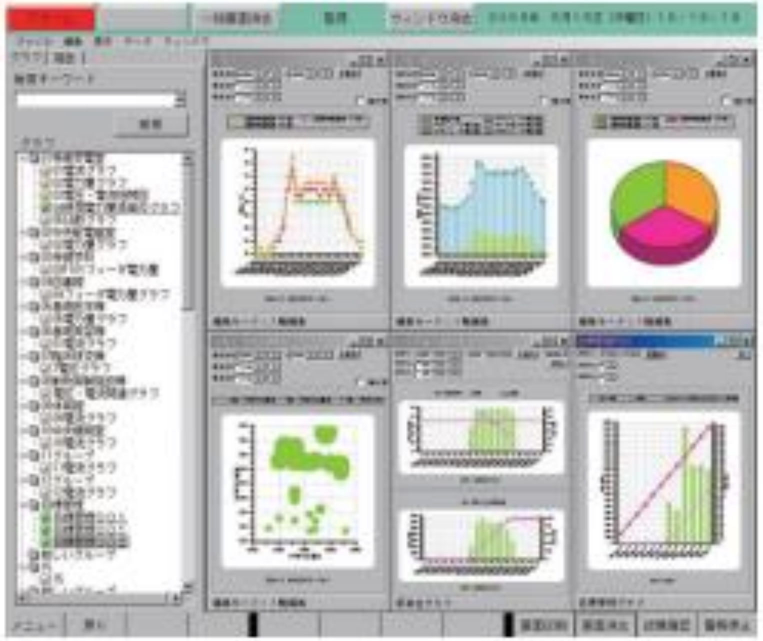
1.2 Smart Energy Management Systems

- A smart function automatically predicts the energy demand (for air-conditioning, lighting, etc.) based on historical demand and meteorological conditions, prepares a minimal waste energy supply plan and then controls the energy supply in accordance with the plan.
- Significant energy use efficiency improvements and cost reductions are realized by integrating the control of multiple systems, such as electric power supply facilities, heat generating facilities and electricity storage systems.
- The smart EMS also uses its automatic response type demand response control function to contribute to electric power demand adjustment in a local community by controlling the energy supply in accordance with the energy demand while maintaining the convenience and comfort of life.

1.2 Smart Energy Management Systems

Monitoring & control screen

Visualization screen



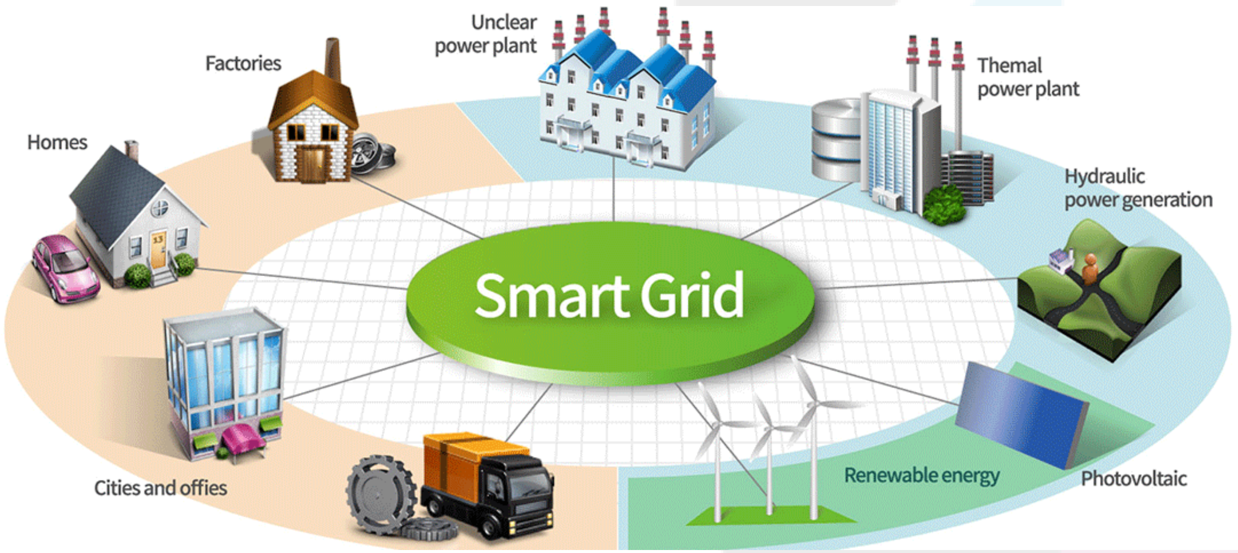
Optimized control display

What exactly is a "Smart" Grid (SG)?

- **Smart as technologically advanced**

Smart comes from digital connectivity between the components.

Being smart, leads to improvement and optimization, being able to provide more services or offer better solutions (i.e. computing power and connectivity).



What exactly is a “Smart” Grid (SG)?

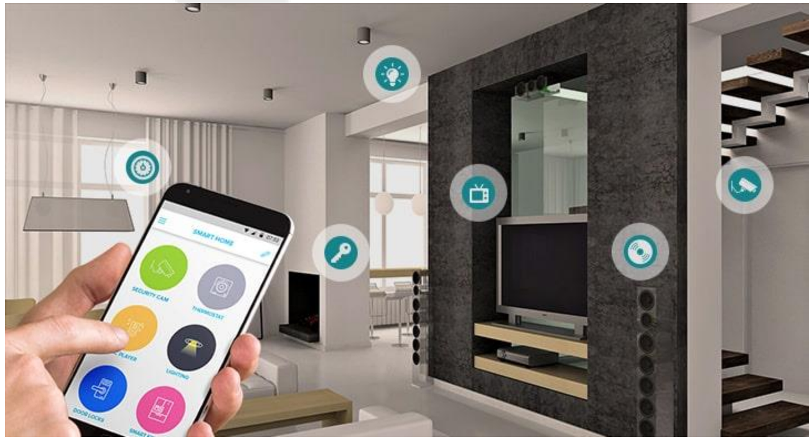
Smart as sustainable

- Sustainability is critical component in reducing our impact on climate change.
- The environmental cost of embodied energy is difficult to estimate. The best way to significantly reduce our environmental impact would be to reduce our need for energy and technology. This requires concrete global behavioral changes.
- “Smart" systems should be those which *reduce our need for transportation and infrastructures (remote working) or help us adopt a more sustainable way of life* (smart thermostats and light switches for example avoiding unnecessary consumption)

What exactly is a "Smart" Grid (SG)?

Smart as enabling

- Among the number of advanced, adaptive services those we call ***smart*** are often those that tighten the ***link*** between humans and their tools.
- Using a combination of learning abilities and adaptiveness, services can become more intuitive over time and getting used by an ever-growing share of the population.
- The main idea : a technology **so seamlessly integrated in our everyday life** and environment that its use becomes natural (i.e. with real time reactivity), and users forget its existence!

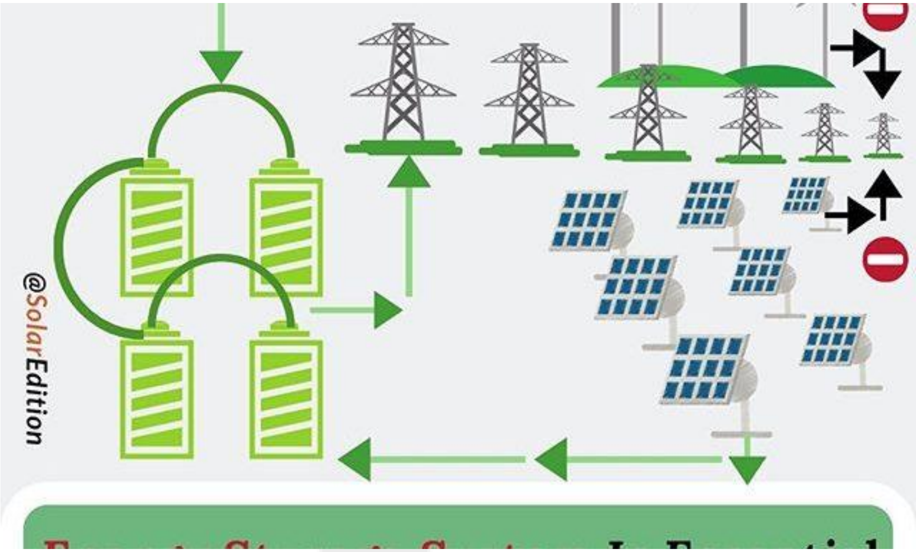


1.3 Smart Grid (SG) definition

- The smart grid ***relies on information technologies*** to achieve a more precise and timely management of the different elements comprising the grid such as:

   1. distributed renewable sources,
   2. local storage systems and
   3. connected residential appliances

- The large number of sensors and connected devices brings new inputs to the management algorithms regarding the state of the grid, and the improving frequency and precision of the measurements allows for a more accurate and reactive control.

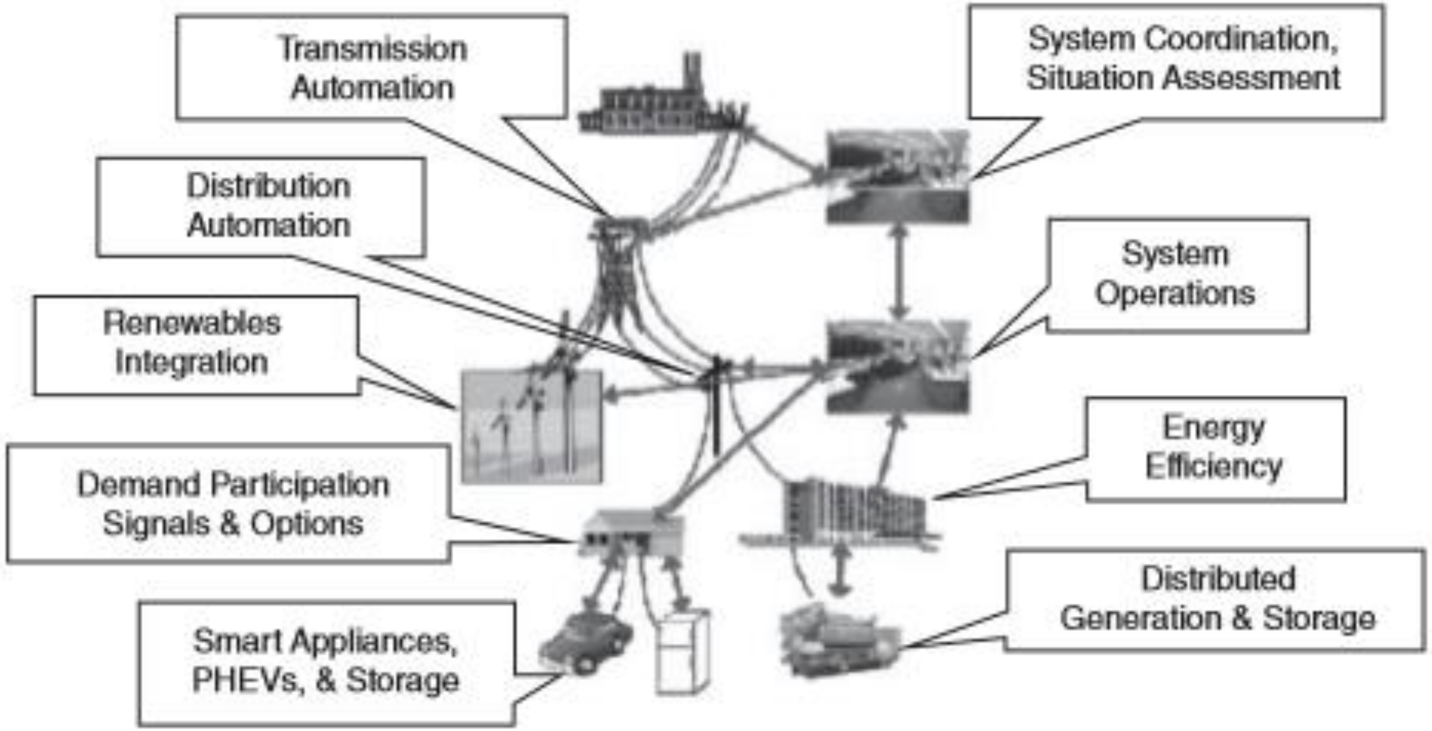


1.3 Smart Grid (SG) definition

- In addition, reducing the carbon emissions of the power grid by allowing the integration of renewable energy sources is one of the main purposes of the smart grid. This can be based on consumption management and eco-friendly behavior, prompted by more intuitive and connected interfaces.
- Furthermore, the deployment of smart meters enables the consumer to be more aware of its active role by interacting easily with the management systems.
- A big part of the smartness of a grid management system *lies in its ability to engage the consumer into a proactive behavior via intuitive interfaces and appealing incentives.*

1.4 Representative architecture

- There are several architectures proposed by the various bodies involved in smart grid development, one of which is as follows:



In this regime, SG is divided in nine areas: *transmission automation, system coordination situation assessment, system operations, distribution automation, renewable integration, energy efficiency, distributed generation and storage, demand participation signals and options, smart appliances, PHEVs, and storage*

1.5 Functions of SG components

- ***Smart Devices interface components***

Smart devices for monitoring and control form part of the generation components' real time information processes. These resources need to be seamlessly integrated in the operation of both centrally distributed and district energy systems

- ***Storage Component***

Due to the variability of renewable energy and the disjoint between peak availability and peak consumption, it is important to find ways to store the generated energy for later use.

- **Transmission Subsystem Component**
- The transmission system that interconnects all major substations and load centers is the backbone of an integrated power system. Transmission lines must tolerate dynamic changes in load and contingency without service disruptions.
- Strategies to achieve smart grid performance at the transmission level include the design of analytical tools and advanced technology with intelligence for performance analysis such as dynamic optimal power flow, robust state estimation, real - time stability assessment, and reliability and market simulation tools.
- Real - time monitoring based on Phasor Measurement Unit (PMU), state estimators sensors, and communication technologies are the transmission subsystem’s intelligent enabling tools for developing smart transmission functionality.

- **Monitoring and Control Technology Component**

Intelligent transmission systems include smart intelligent networks, self-monitoring and self-healing, and the adaptability and predictability of generation and demand robust enough to handle congestion, instability, and reliability issues. This new resilient grid has to withstand shock (durability and reliability) and be reliable to provide real-time changes in its use.

- **Intelligent Grid Distribution Subsystem Component**

The distribution system is the final stage in the transmission of power to end users. Primary feeders at this voltage level supply small industrial customers and secondary distribution feeders supply residential and commercial customers. At the distribution level, intelligent support schemes will have monitoring capabilities for automation using smart meters, communication links between consumers and utility control, energy management components, and AMI (Advanced Metering Infrastructure).

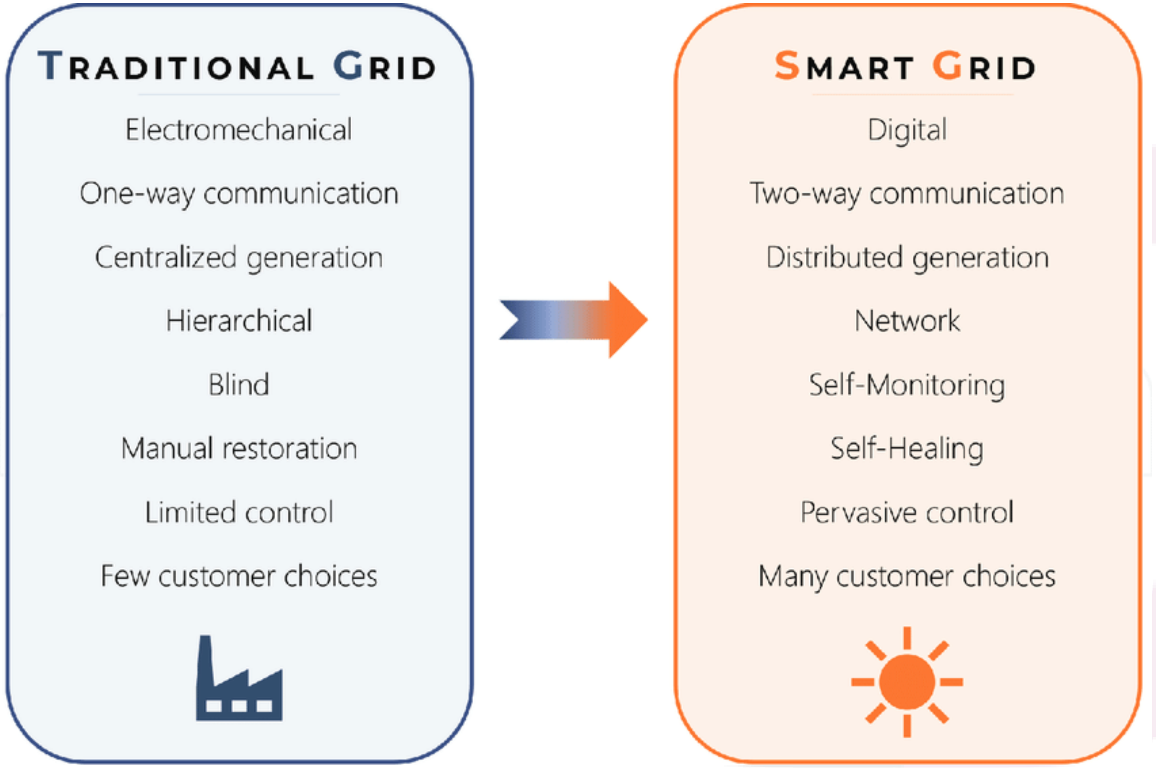
- **Demand Side Management Component**

Energy demand management, also known as demand-side management (DSM) or demand-side response (DSR), is the modification of consumer demand for energy through various methods such as financial incentives and behavioral change through education.

DSM provides reduced emissions in fuel production, lower costs, and contributes to reliability of generation. These options have an overall impact on the utility load curve. A standard protocol for customer delivery with two - way information highway technologies as the enabler is needed. Plug - and - play, smart energy buildings and smart homes, demand - side meters, clean air requirements, and customer interfaces for better energy efficiency will be in place.

1.6 Basic concepts of a Smart Power Grid

- In a classical power grid, a fixed price is charged to energy users. However, the cost of energy is the highest during the daily peak load operation. The classical power system operation has *no control over the loads except in an emergency situation* when a portion of the loads can be dropped as needed to balance the power grid generation with its loads.
- For an efficient smart power grid system design and operation, substantial infrastructure investment in the form of a communication system, cyber network, sensors, and smart meters must be installed to curtail the system peak loads when the cost of electric energy is highest.

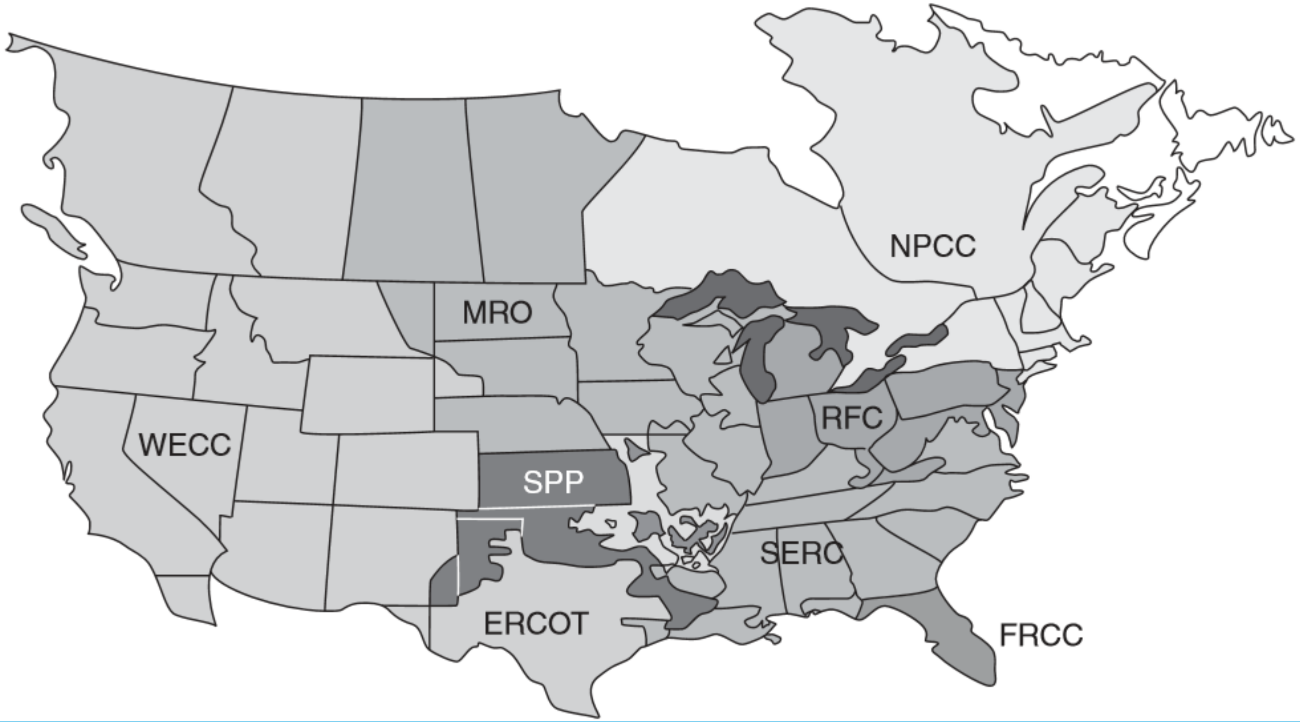


1.6 Basic concepts of a Smart Power Grid

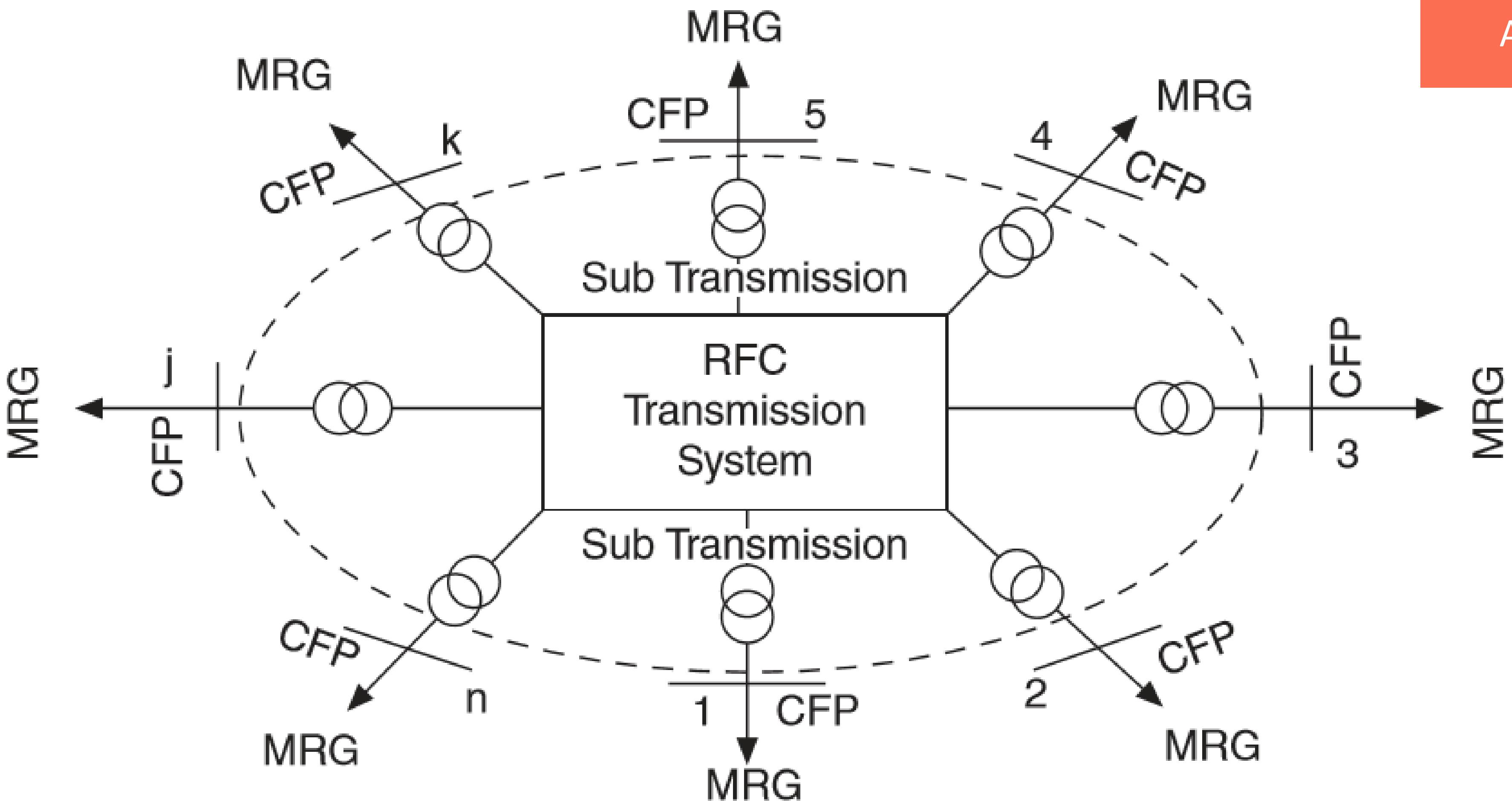
- The smart power grid consists of a sensing, monitoring, and control system that provides end users with the cost of energy at any moment using real-time pricing.
- In addition, the advanced control systems of smart metering give the energy users the ability to respond to real-time pricing.
- Furthermore, the smart power grid supplies the platform for the use of renewable green energy sources and adequate emergency power for major metropolitan load centers.
- It is robust against a complete blackout of the interconnected power grids due to man-made events or environmental instabilities. It also allows for the break-up of the interconnected power grid into smaller, regional clusters.
- And most important the smart power grid **enables every energy user to become an energy producer by giving the user the choice of PV or wind energy, fuel cells, and combined heat and power (CHP) energy sources and to participate in the energy market!**

- The bulk power grid of the United States and many other countries is already operating as a large interconnected network. The mission of the North American Electric Reliability Corporation (NERC) is to ensure the reliability and security of the America's bulk power grid. Figure below depicts the North American electric reliability centers.

North American Electric Reliability Centers (NERC). ERCOT, Electric Reliability Council of Texas; FRCC, Florida Reliability Coordinating Council; MRO, Midwest Reliability Organization; NPCC, Northeast Power Coordinating Council, Inc.; RFC, Reliability First Corporation; SERC, SERC Reliability Corporation; SPP, Southwest Power Pool, Inc.; WECC, Western Electricity Coordinating Council



A Cyber - Controlled Smart Grid



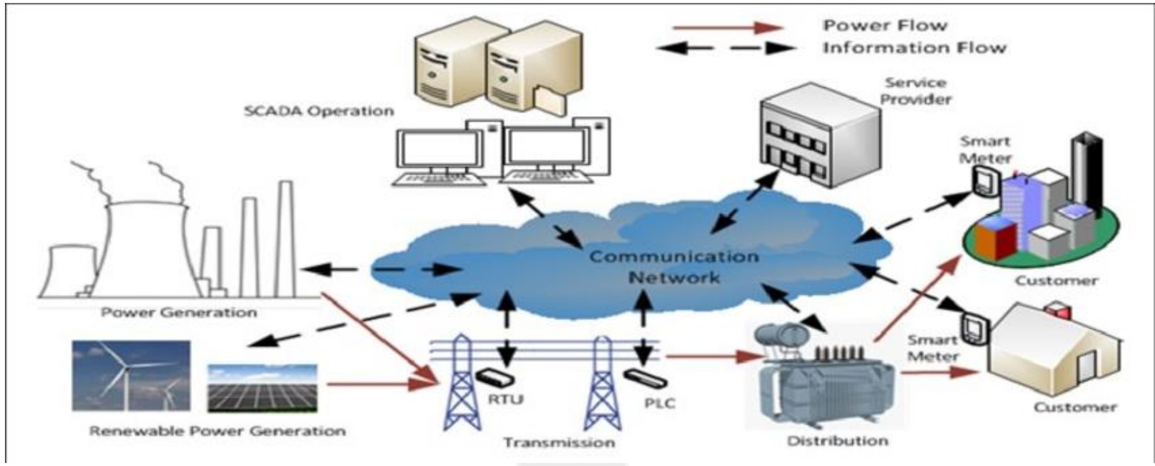
CFP: Cyber Fusion Point
MRG: Microgrid Renewable Green Energy System

Fig 4.17 from Keyhani, Ali. *Design of smart power grid renewable energy systems*. John Wiley & Sons, 2016.

1.6 Basic concepts of a Smart Power Grid

- The cyber- fusion point (CFP) represents a node of the smart grid system where the renewable green energy system is connected to large - scale interconnected systems. The U.S. interconnected system has eight regional reliability centers (see Figure in slide 21).
- It is expected that renewable microgrids will be connections of regional reliability centers such as Reliability First Corporation (RFC) transmission systems.
- The CFP is the node in the system that receives data from upstream, i.e., from the interconnected network, and downstream, i.e., from the microgrid renewable green energy (MRG) system and its associated smart metering systems. The CFP node is the smart node of the system where the status of the network is evaluated and controlled, and where economic decisions are made as to how to operate the local MRG system. A CFP also evaluates whether its MRG system should be operated as an independent grid system or as a grid system separate from the large interconnected system.

- A cyber system is the backbone of the communication system for the collection of data on the status of the interconnected network system.
- Two-way communication is a key characteristic of the smart power grid energy system. It enables end users to adjust the time of their energy usage for nonessential activities based on the expected real - time price of energy.
- The knowledge gained from smart meters permits the power grid operators to spot power outages more quickly and smooth demand in response to real - time pricing as the cost of power varies during the day.

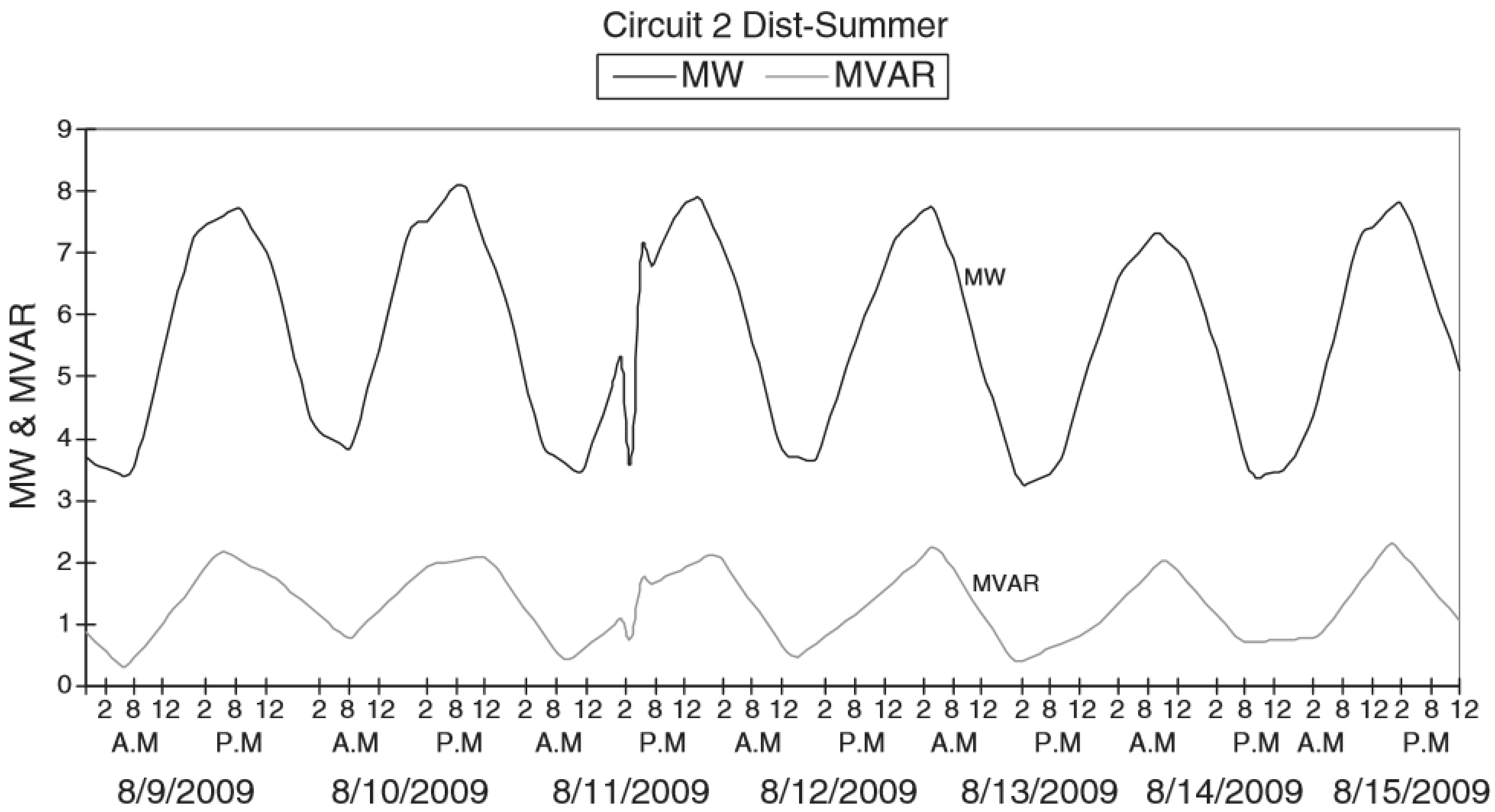


- The cyber control of a smart grid is currently the subject of research by many disciplines in electrical and computer engineering.
- It requires a control system that analyzes the performance of the power grid using distributed, autonomous, and intelligent controllers. The cyber system will learn on - line from the sensors, the smart grid, and microgrid states.
- The control system monitors for possible impeding failure. By sensor measurements and monitoring, the cyber control system governs grid behavior based on real-time data in the face of ever-changing operating conditions and new equipment.
- The system uses electronic switches that control multiple MRG systems with varying costs of generation and reliability. As a result, a cyber- controlled smart grid requires consumers to pay the real- time price of produced electric power.

The Cost of Electric Energy in 2015

Energy Source	Cost per Kilowatt Hour (Cents)	Typical Uses	Typical Installation Size
Solar energy (photovoltaics)	20–40	Base load power source	1–10,000 kW
Microturbines	10–15	Can be used in base load, peaking or cogeneration applications	30–300 kW
Fuel cells	10–15	Rural (off-grid) power Transportation appropriate for base load applications	1–200 kW
Wind turbines	5–10		5–10 MW
Internal combustion engines	1.5–3.5	Well-established, long history as back up or in peaking applications	50 kW–5 MW
Central power generation	1.7–3.7	Base load/peaking electricity generation	500–3000 MW

- Figure in slide 28 shows that the feeder maximum load and minimum load is changing by a factor of 2 over 24 hours. The local power company must use many types of electric power sources to match the system generation to the system load.
- The power flow into this load center is supplied by 345 kV and 138 kV transmission systems. The area load demands are satisfied by the secondary and tertiary windings of transformers rated at 138/69/12. Industrial loads are served at 138/69/23 kV. The bus load is the power flowing into the primary windings of the transformers connected to 23kV.
- The power flows from higher voltage systems to lower voltage systems. Therefore, the bus load can be defined as 138 kV and/ or 345 kV transformer loads.



The Hourly Loads of a Distribution Feeder of a Midwestern Power Company

- An important factor affecting the load demands and real time pricing is the effect of weather and its ensuing rapid increase in load demands. To separate weather - induced bus load, we use the average bus load when weather conditions are normal and subtract when weather conditions are above normal.
- The recursive mean and variance of {Y(.)} can be computed based on the following Equations:

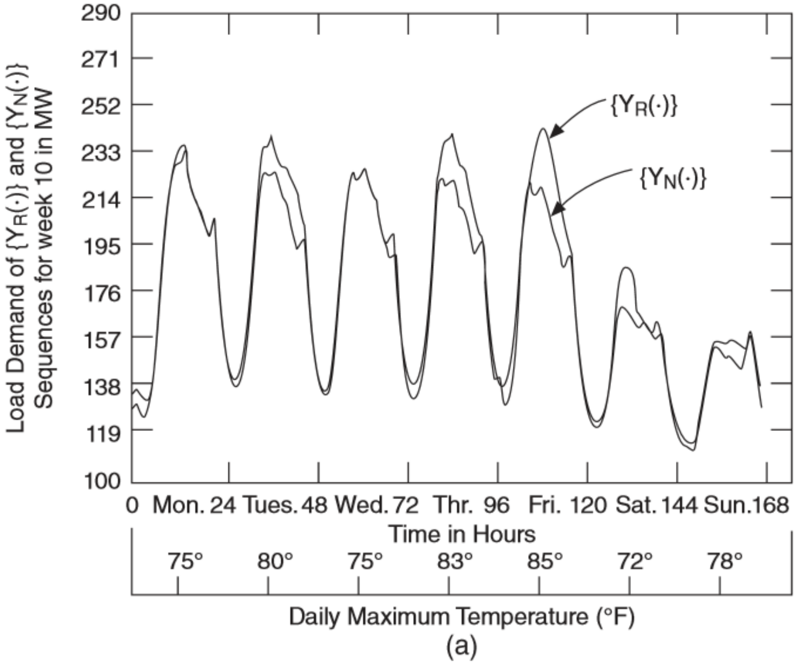
$$\bar{Y}(K+1)=\bar{Y}(K)+\frac{Y(K+1)-\bar{Y}(K)}{K+1}$$

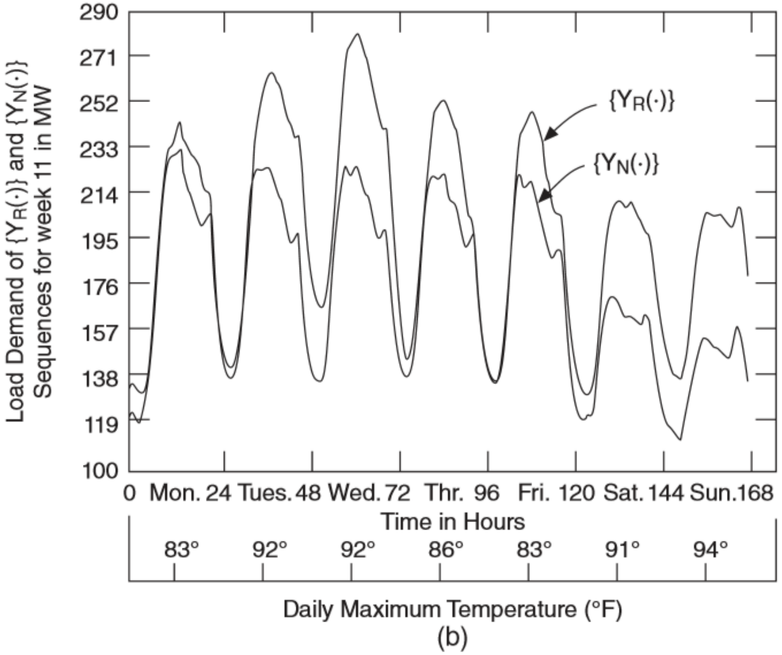
$$\sigma y^2(K+1)=\frac{K}{K+1}\sigma y^2(K)+\frac{[Y(K+1)-\bar{Y}(K+1)]^2}{K}$$

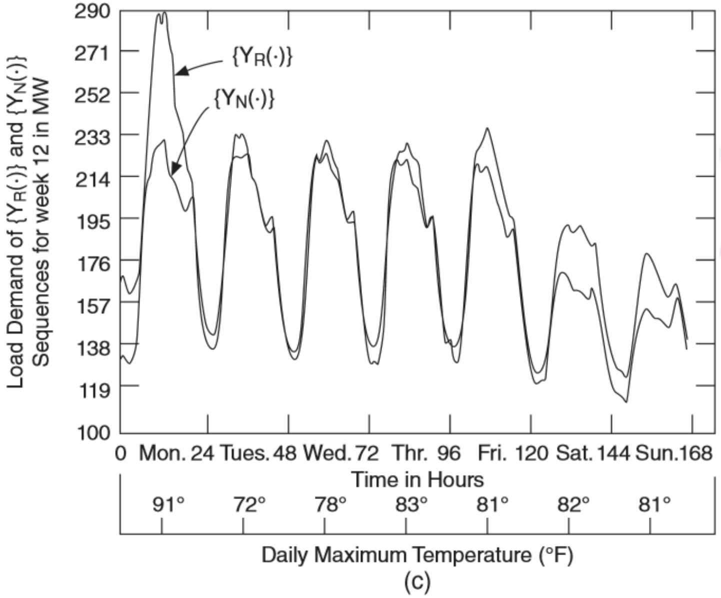
- The weather effect on the load sequence, holidays, and other unknown conditions, which cause the load demand sequence to be higher or lower than a given nominal mean load profile, is subtracted from the recorded data.
- By removing the component of $\{Y_R\ (.)\}$, weather - induced load demand due to the weather effect, we generate a new sequence designated as the nominal load sequence $\{Y_N(.)\}$. The effect of weather conditions on the load depends on temperature, humidity, wind speed, and illumination.
- However, to demonstrate the basic concept, only the weighted average, maximum and minimum temperature that were recorded, were used. Therefore, the effect of weather condition on the load is expressed in terms of temperature.

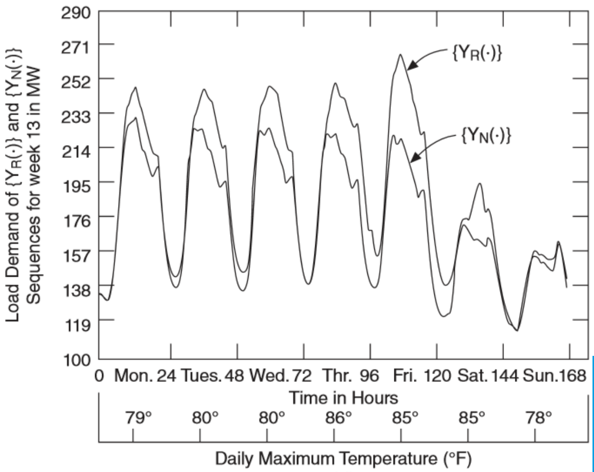
- A weather- sensitive load is present when the daily temperature, T, is outside of the comfort range of Tmin< T < Tmax where Tmin and Tmax are the lower and upper limits of the comfort range.
- This suggests that the nominal nonweather sensitive load sequence $\{Y_N\ (.)\}$ is assumed to be equal to the sequence $\{\ Y_R\ (\ .)\}$ when the temperature is within the comfort range, and sudden load changes due to outages or special events have not occurred.

1.6 Basic concepts of a Smart Power Grid



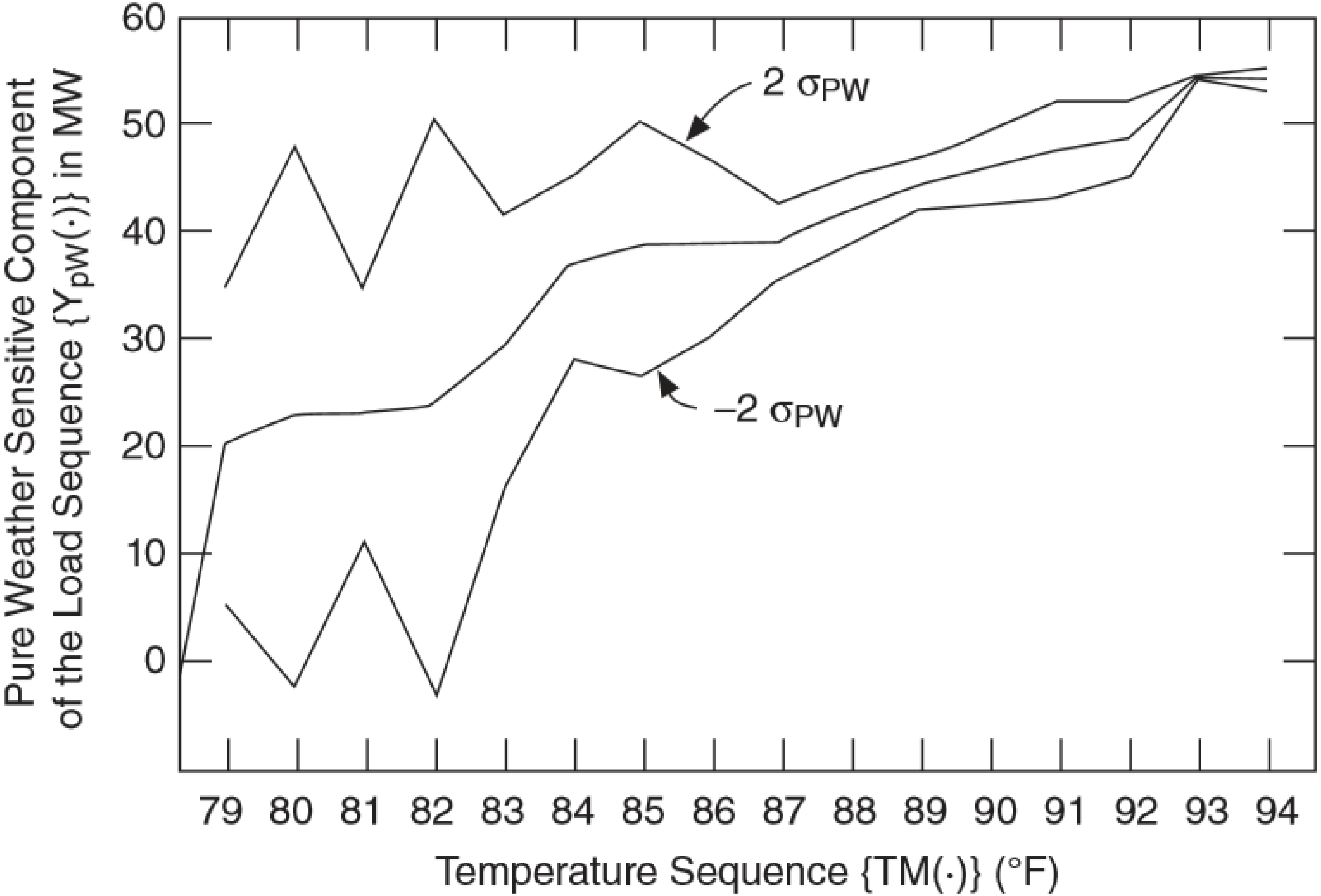






Plot of $\{Y_R(.)\}$ and $\{Y_N(.)\}$ for weeks 10, 11, 12, and 13

- Previous Figs show the plots of {Y_R (.)} and {Y_N (.)} load sequences for week 10, 11, 12, and 13 bus loads. It can be seen that the general weekly profile of weather - sensitive load sequence {Y_R (.)} and nominal load (non-weather sensitive) sequence {Y_N (.)} are essentially the same when the daily temperature is normal. However, when the daily temperature is high, a weather - induced load is superimposed on the {Y_N (.)} sequence.
- The procedure is based on computing an average relationship between the temperature and the pure weather - induced component of the load, which is designated as Y_{PW} . The sequence { Y_{PW} (.)} is generated where each member of { Y_{PW} (.)} is a mean value of the pure weather - sensitive component of the load at a given temperature.



The Mean and Standard Deviation of a Pure Weather - Sensitive Load versus Temperature

- Historically, power grid companies operated the power system as a public service. They provided reliable electric power at a constant price regardless of changing conditions. Their systems used additional spinning reserve units to serve the unexpected loading and outages due to the loss of equipment. However, in an age of global climate change, this kind of service cannot be provided without severe environmental degradation.
- A power grid operator schedules generation sources based on the cost of energy. However, the weather-sensitive load component adds substantial uncertainty in planning load – generation balance. As can be expected, the least costly units are scheduled to satisfy the base loads. The more costly units are scheduled to satisfy the time - changing loads. Therefore, the price of electric energy is continuously changing as load demands are changing. If real - time pricing is implemented, the variable electric rates must be used for the privilege of reliable electrical service during high- demand conditions.

1.7 The load factor

- The load factor is one of the key factors that determines the price of electricity. The load factor is the ratio of a customer 's average power demand to its peak demand. As has been observed, the load demands vary during the day.
- The cost of peak power demand is substantially higher than the average power demand. Therefore, the cost of power demand changes with the time of day. The term "real - time pricing" refers to the minute - by - minute price of electric power as the energy control center commits the scheduled generators to the production of electric power.
- The load factor determines the price of power in an electric power grid.

$$Load\ factor\,(\%) = \frac{Average\ Power}{Peak\ Power} \times 100$$

1.7 The load factor

- The average power is defined as the amount of power consumption during a period. The peak power is defined as the amount of maximum power consumption during the same period. The load factor can be calculated based on daily, monthly, or yearly cycles.
- For system planning, the load factor is calculated on a monthly or annual basis. The facility investments must be made so that the system can handle the maximum demand. Therefore, it is desirable to have a low maximum demand.
- On the other hand, because revenues are generated in proportion to the average demand, it is desirable to have a high average demand. Therefore, a ***desirable load factor is close to one,*** so that peak demand and average demand are close to each other.

Example 1.

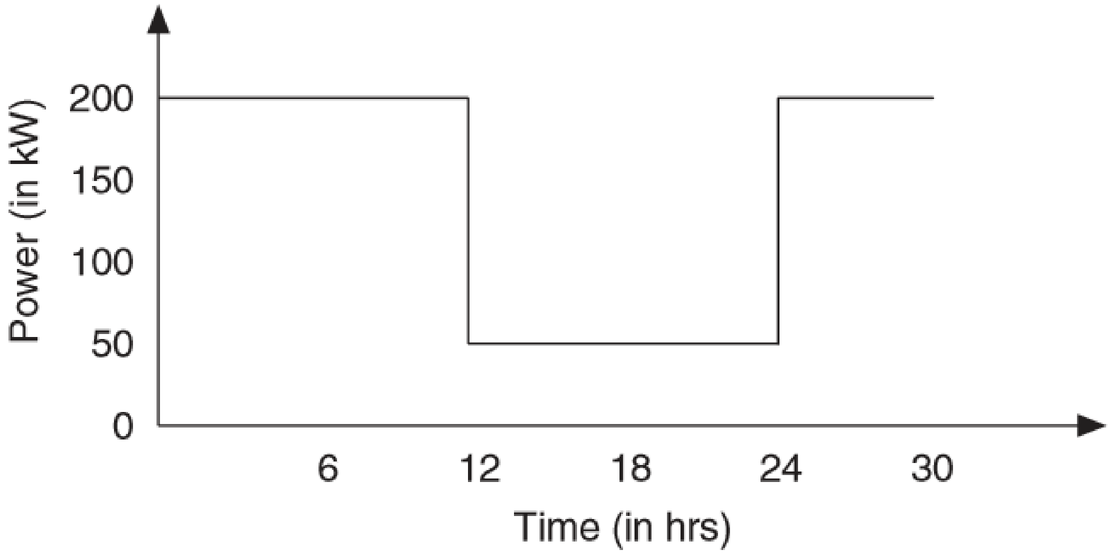
- An industrial site has a constant power demand of 100 kW over a year of energy consumption. Compute the customer load factor over one year of providing energy to this site.

- Total energy= $8760\ \text{h/yr} \times 100\ \text{kW} = 876{,}000\ \text{kWh/yr}$

- Because the power demand is constant the average and peak is the same. Therefore, the load factor of this customer is 100%.

Example 2.

A commercial site has peak demand of 200 kW during 12 hours a day and an average demand of 50 kW demand the rest of a day. Compute the customer load factor over one year of providing energy to this site. Explain the associated cost of providing energy to the industrial site and the commercial site.



Load for 24 hours.

Example 2.

$$\text{The average power} = \frac{\sum power_i \times time_i}{\sum time_i} = \frac{200 \times 12 + 50 \times 12}{12 + 12} = 125 \text{ kW}$$

$$\text{Load factor} = \frac{\text{average power}}{\text{peak power}} = \frac{125}{200} \times 100 = 62.5\%$$

When the load factor is close to unity (100%), the generating plant is efficiently used. The cost of supplying power to the load is more when the load factor is low.

- At a commercial site with a low load factor, say in the range of 50%, the power grid would need twice as much installed equipment and resources to serve the site.
- The lower load factor means that the price must be adjusted to recuperate the extra costs. Because the industrial site and commercial site use the same amount of kW, the same price is charged the two sites.
- However, the smart meter, in conjunction with real - time pricing can provide an incentive for efficiency and load demand control. The users as stakeholders would be encouraged to control the loads during peak power demands by shifting the usage at times when prices are favorable.
- Furthermore, the end users have a high incentive to participate by installing local green energy sources such as wind and PV.

1.7.1 The Load Factor and Real - Time Pricing

- Real - time pricing was introduced by F. Schweppes in July 1978 during an energy crisis. A simple analysis of the cost to the supplier per unit of energy delivered explains the relationship between cost and plant utilization. The real - time price of electricity is a function of load factor, load demand, and unexpected events.
- The first cost is the utilization of a power plant and its operating costs. To build a large plant, many issues must be addressed. In a regulated market, large plants take years to build and are located far away from load centers; electric power is transferred by long transmission lines.
- Normally, coal - fired power plants are built close to a coal mine. From an operational viewpoint, the sudden loss of a large plant creates instant real-time price change in the power market because the allocated real - time reserve is limited by cost.

1.7.1 The Load Factor and Real - Time Pricing

- Small power plants are normally gas fired; they are built over a short time and their construction costs can be accurately estimated. Gas - fired plants can be placed close to load centers because of their smaller size.
- Furthermore, when plants are close to load centers they have lower system losses and better system security. They are more reliable and have fewer adverse consequences when they are subjected to sudden outage.
- Cogeneration (or combined cycle that recycle some of the heat for example) facilities are attractive because of higher efficiency. Plants fueled by renewable energy sources are attractive as well because of their low operating cost. Due to many sources of power and their associated cost, the cost of real- time power changes as sources of electric energy to supply the system load changes.

- **Example 3.**

Suppose a PV plant of 1000 kW capacity is constructed for $500 per kW. Compute the cost of energy per kWh to the end users for one year of operation at full capacity if the total cost on investment is to be recovered in 2 years when the PV plant operates 6 hours a day on the average for 2 years and the cost of production is negligible.

The energy consumed in year = $\textit{power capacity} \times \textit{time in hours}$

$$1000 \times 365 \times 6 = 2{,}190 \text{ MWh}$$

Let the price of 1 kWh of energy be = $/kWh

The investment cost = $\textit{capacity} \times \textit{cost per unit capacity} = 1000 \times 500 = 500{,}000$

- **Example 3.**

Therefore the energy consumed for 2 years= 2x2,190=4,380MWh

$$4,380\times10^3\times x=500,000$$

$$x=\frac{500,000}{4,380\times10^3}=\$0.1142\ \mathrm{kWh}$$

Let us introduce the cost of fuel, labor, and maintenance in a load factor calculation.

$$EUC=VC+\frac{amortized\ fixed\ cost}{LF}$$

In this Equation, the term VC defines variable cost associated with fuel and other cost of plant operation and EUC represents the energy unit cost in cents per kWh.

- **Example 4.**

Suppose a natural gas plant of 1000 kW capacity is constructed for \$300 per kW. Assume the variable cost, VC, is 2 cents per kWh. Perform the following:

i) Compute the cost of electric energy to end users if the 100% of installed capacity is used 24 hours a day over 5 years.

ii) Compute the cost of electric energy to end users if the 100% of installed capacity is used 12 hours and 50% of installed capacity is used for the rest of a day over 5 years.

iii) Plot the energy unit cost versus the load factor, LF from 0 to 1.

- **Example 4.**

The investment cost $= capacity \times cost \cdot per\ unit\ capacity$

$$= 1000 \times 300 = \$300,000$$

Energy consumed over a period of 5 years at full capacity $= 1000 \times 24 \times 365 \times 5$

$$= 43,800\ \mathrm{MWh}$$

If this cost is distributed over 5 years, the amortized fixed cost

$$= \frac{300,000}{43,800 \times 10^3} = 0.007$$

- Example 4.

i) Load factor = 1

$$EUC = VC + \frac{amortized\ fixed\ cost}{LF}$$

$$EUC = 0.02 + \frac{0.007}{1} = \$0.027 / \text{kWh}$$

ii) The average power

$$= \frac{\sum power_i \times time_i}{\sum time_i}$$

$$= \frac{1000 \times 1 \times 12 + 1000 \times 0.5 \times 12}{12 + 12} = 750 \text{ kW}$$

$$\text{Load factor} = \frac{average\ power}{peak\ power} = \frac{750}{1000} \times 100 = 75\%$$

$$EUC = 0.02 + \frac{0.007}{0.75} = \$0.029 \text{ kWh}$$

- **Example 4.**
- To compute the energy unit cost versus the load factor, LF from 0 to 1, a MATLAB M-file is developed as presented below:

```
% PLOT OF EUC
clc; clear all;
LF = 0.01:.01:1;               % defining the range of load factor

VC = 0.02;                     % variable cost
A_FC = 0.007;                  % amortized fixed cost
EUC = VC + A_FC./LF;           % defining EUC in $/kWh
EUC = EUC*100;                 % converting into cents/kWh

plot(LF,EUC)
grid on;                       % labeling the axes
xlabel('Load Factor');
ylabel('EUC(in cent/kWh)');
title('EUC vs Load Factor');
```

Plot:

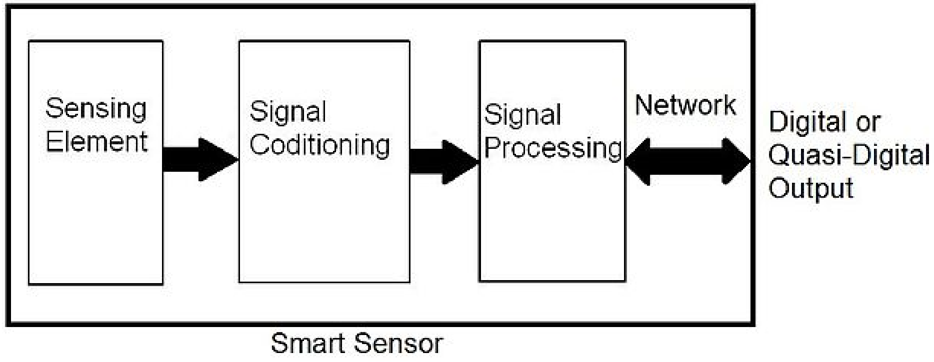
1.8 A cyber-controlled Smart Grid

- A cyber - controlled smart grid consists of many distributed generation stations in the form of microgrids. The microgrids incorporate intelligent load control equipment in their design, operation, and communication. This enables the energy end users and the microgrids serving them to better control energy usage.
- Smart appliances such as refrigerators, washing machines, dishwashers, and microwaves can be turned off if the energy end user selects to reduce energy use and costs. This is done by connecting the smart appliances to the energy management systems in smart buildings.
- Advanced communications capabilities in conjunction with smart meters and smart appliances enable the energy end users with the tools to take advantage of real - time electricity pricing and incentive - based load control.

- With ***real - time pricing,*** the energy end users would have an incentive to become energy producers through green energy. As real - time prices take hold, commercial and industrial units are expected to generate their own energy and sell their extra power back to the power grid.
- *Cyber* - controlled smart grid technology has three important elements: sensing and measurement tools, a smart transducer, and an integrated communication system. These elements monitor the state of the power system by measuring line flows, bus voltages, magnitude, and phase angle using phasor measurement technology and state estimation.
- The technology is based on advanced digital technology such as microcontrollers/digital signal processors. The digital technology facilitates wide - area monitoring systems, real - time line rating, and temperature monitoring combined with real - time thermal rating systems

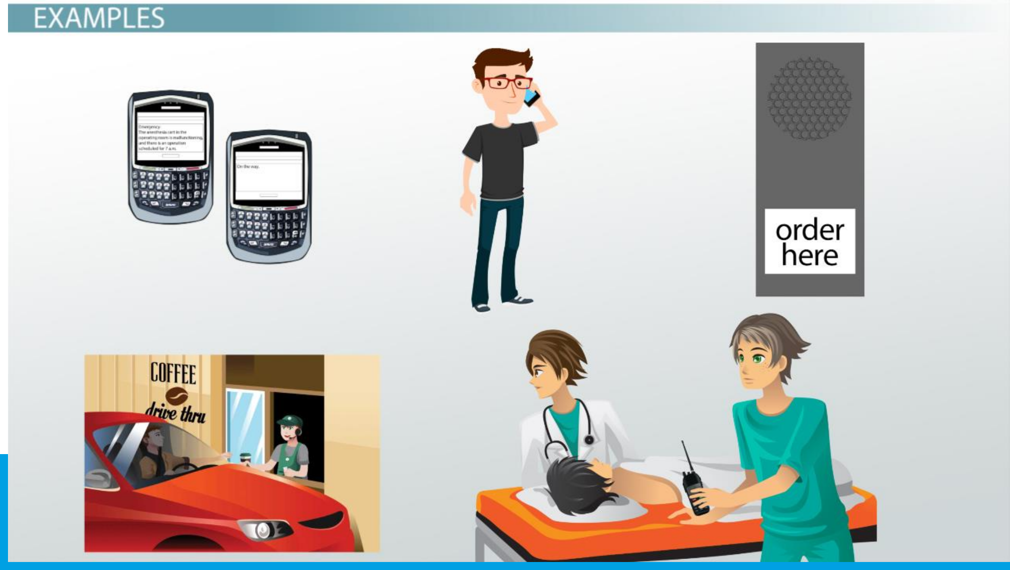
1.8 A cyber-controlled Smart Grid

- Transducers play a central role in automatic computerized data acquisition and monitoring of smart grid power systems. A smart transducer combines a digital sensor, a processing unit, and a communication interface.
- The smart/controller transducer accepts standardized commands and issues control signals. It is able to locally implement the control action based on feedback at the transducer interface. The utilization of low - cost smart transducers is rapidly increasing in embedded control systems in smart grid monitoring and control.



1.8 A cyber-controlled Smart Grid

- Real - time, two - way communication is enabling a new paradigm in the smart grid system. It enables the end users to install green energy sources and to sell energy back to the grid through ***net metering.***
- Smart meters facilitate the communication between the customers by providing the real price by the supplier. The customers track energy use and see the expected price of energy (can be a day ahead) along with the real- time price of energy. The end user is made aware of the potential savings of curtailing energy use when the energy system is under stress.



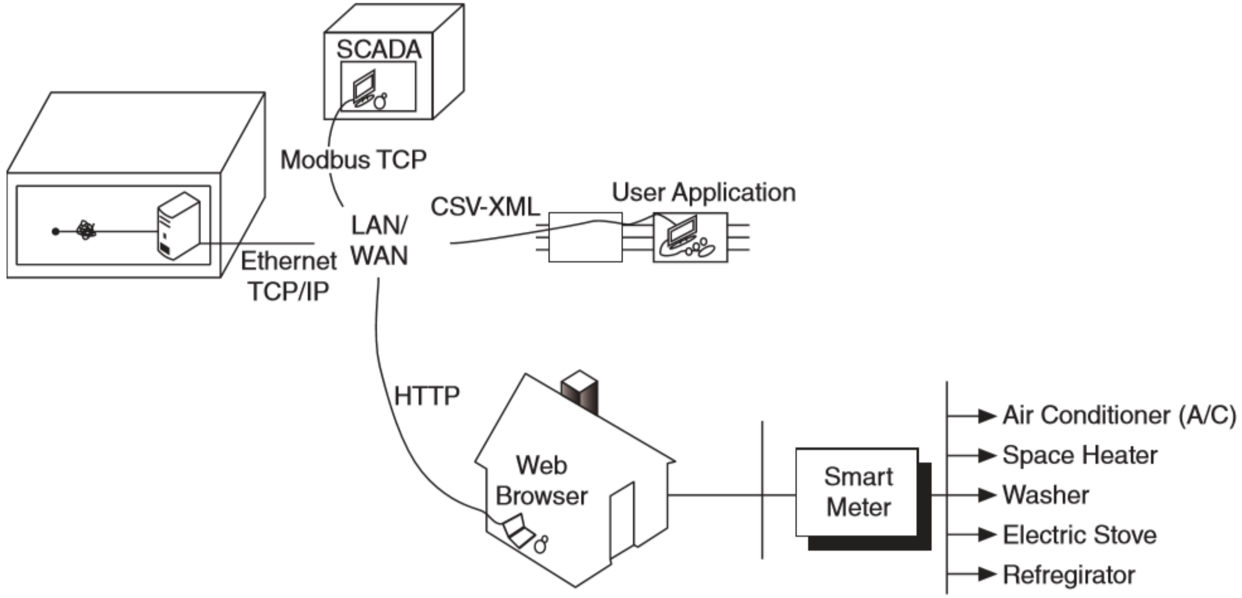
1.8 A cyber-controlled Smart Grid

- A smart meter allows the system operator to control the system loads. Load control ultimately provides new markets for local generation in the form of renewable green energy sources. With the installation of smart meters (i.e., a ***net metering*** system), end users can produce green energy and sell their extra power to their local power grid.
- As more customers use a net metering system, a substantial change in energy demand will result. Residential, commercial, and industrial customers will install PV, wind systems, and other micro-generation technologies and store energy as independent power producers.
- The energy management systems of smart buildings with their own renewable power sources and CHP is likely the trend of the future. With the installation of an advanced net metering system, every node of the system will be able to buy and sell electric power.
- The use of real - time prices will facilitate the control of frequency and tie - line deviations in a smart grid electric power system. Under the grid emergency operation, the real- time pricing will provide a feedback signal as the basis of an economic load/shedding policy to assist the direct stabilizing control for a smart grid.

- Real - time pricing can be integrated with demand response to match the system load demand and generation in real- time. This will facilitate coordinating demand to flatten a sudden change in energy use. If the sudden surge in demand is not satisfied, it will result in the cascading collapse of the power grid.
- In demand response control, these spikes can be eliminated without the cost of adding spinning reserve generators. It will also reduce maintenance and extend the life of equipment.
- Energy users can reduce their energy bills by using their smart meters to program and operate their low priority household appliances only when energy is at its cheapest!

1.8 A cyber-controlled Smart Grid

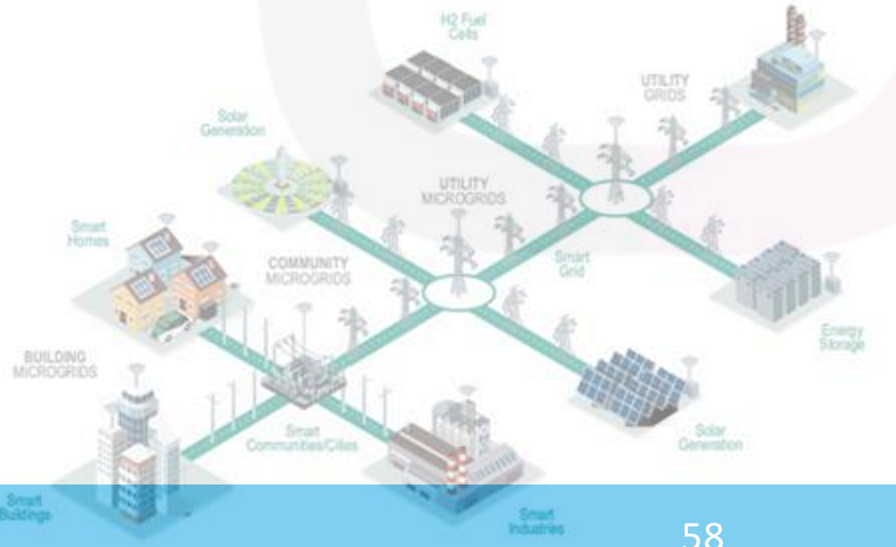
- Figure in slide 22 depicts the MRG system. The MRG system's energy management system (EMS) communicates with individual smart meters located at residential, commercial, and industrial customer sites.
- Smart meters control loads, such as air - conditioning systems, electric ranges, electric water heaters, electric space heaters, refrigerators, washers, and dryers using Ethernet TCP/ IP sensors, transducers, and communication protocols.



Ethernet TCP/IP Sensors, Transducers, and Communication Protocol for Load Control.

1.9 Smart Grid development

- Global warming and the environmental impact of coal-based power generation are changing the design and operation of the power grid. The industry is experiencing a gradual transformation that will have a long - term effect on the development of the infrastructure for generating, transmitting, and distributing power. This fundamental change will incorporate renewable green energy sources in a new distributed generation program based on increased levels of distributed monitoring, automation, and control as well as new sensors.
- Power grid control will rely on data and information collected on each microgrid for decentralized control. In return, the microgrids and interconnected power grid will be able to operate as a more reliable, efficient, and secure energy supplier.



	Current Grid	Smart Grid
System communications	Limited to power companies	Expanded, real-time
Interaction with energy users	Limited to large energy users	Extensive two-way communications
Operation & maintenance	Manual and dispatching	Distributed monitoring and diagnostics, predictive
Generation	Centralized	Centralized and distributed, substantial renewable resources, energy storage
Power flow control	Limited	More extensive
Reliability	Based on static, off-line models and simulations	Proactive, real-time predictions, more actual system data
Restoration	Manual	Decentralized control
Topology	Mainly radial	Network

Comparison of the Current Grid and the Smart Grid

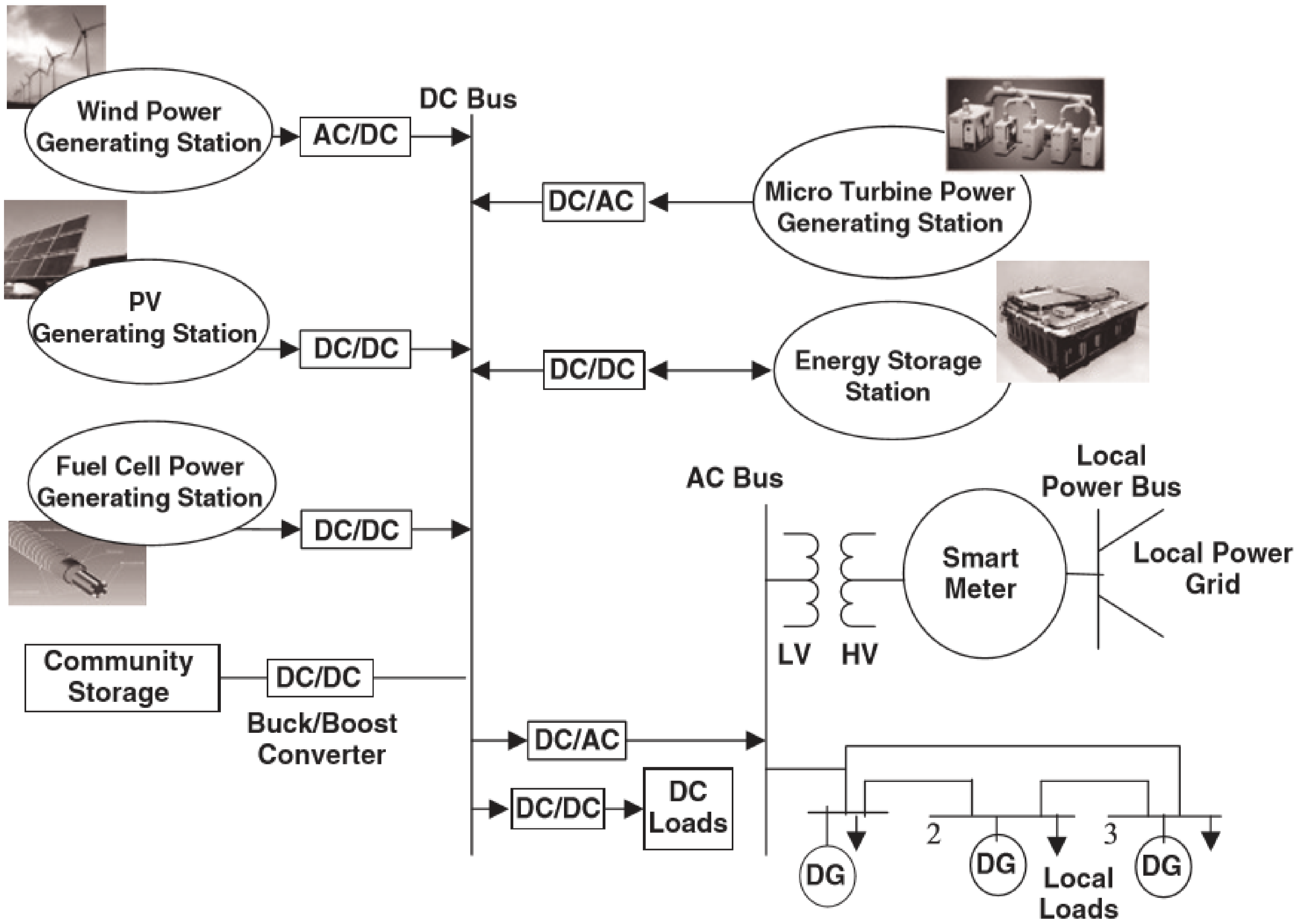
1.9 Smart Grid development

- The implementation of an advanced metering infrastructure provides real time pricing to the energy end users. In parallel, the penetration of renewable energy sources is providing a platform for autonomous control or local control of connected microgrids to the local power grid.
- A distributed autonomous control will provide reliability through fault detection, isolation, and restoration. The autonomous control and real - time pricing also delivers efficiency in feeder voltage to minimize feeder losses and to reduce feeder peak demand of plug - in electric vehicles.
- The maturing storage technology will provide community energy storage, which becomes yet another important element for microgrid control and allows the energy user to become an energy producer. These interrelated technologies require a coordinated modeling, simulation, and analysis system to achieve the benefits of a smart power grid.

1.10 Smart Micro Grid Renewable (MRG) energy systems

- Figures in next slides present the DC and AC architectures of MRG systems. The MRG systems will also include cyber communication systems consisting of smart sensors for monitoring, controlling, and tracking the normal, alert, emergency, and restorative states of systems.
- Smart meters of the MRG system are connected to a large interconnected power grid. The MRG system is also designed to provide an intelligent grid optimization manager that would allow control of various customer loads based on pricing signals and grid stress.
- Smart meters control devices at the customer’s location by changing their use of power. Smart meters have the ability to shed customer load and allow distributed generation to come on - line, when the price of power is above a specified level.

1.10 Smart Micro Grid Renewable energy systems

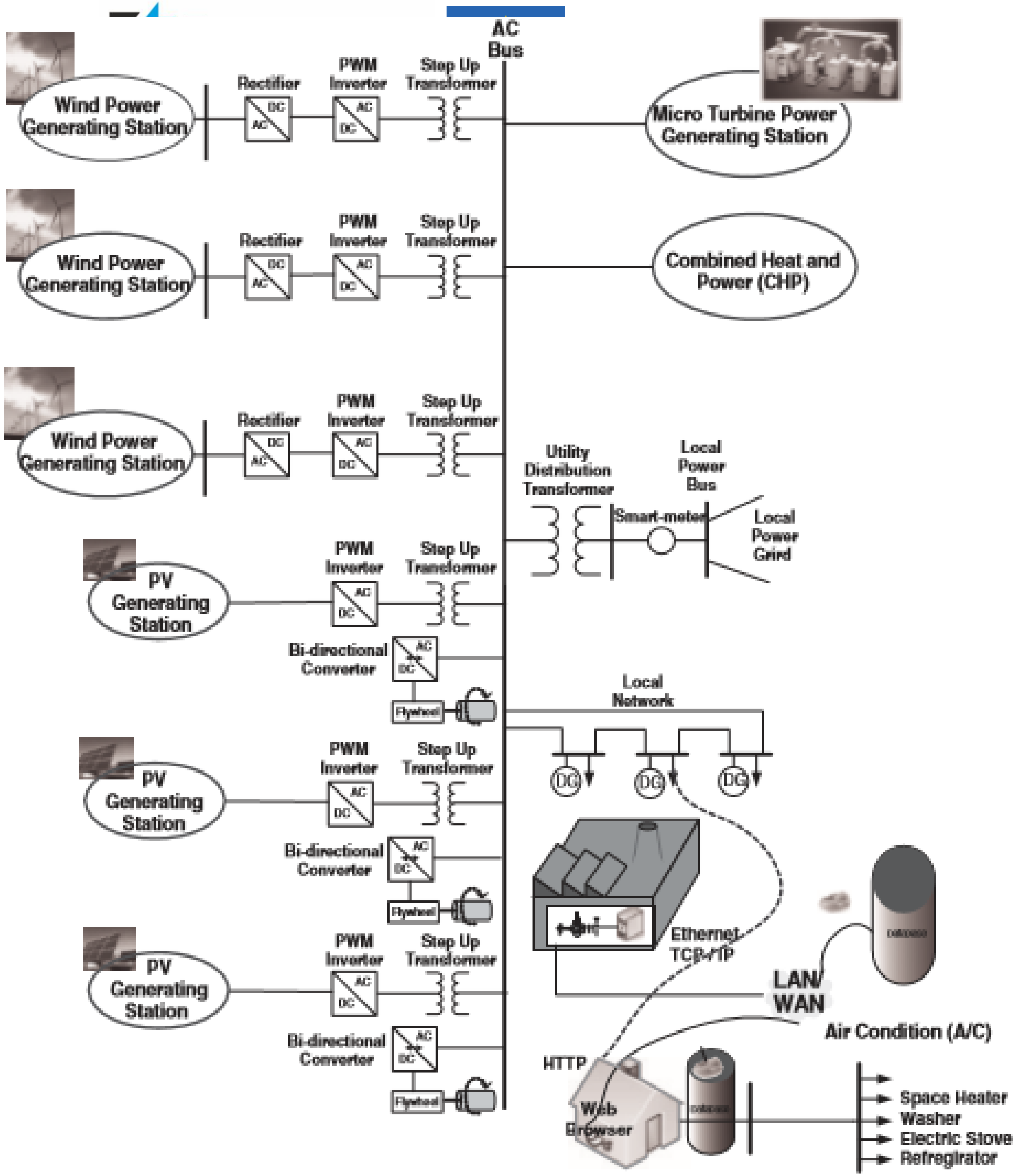


The DC Architecture of a Microgrid Renewable Green Energy (MRG) Distributed Generation (DG) System

1.10 Smart Micro Grid Renewable (MRG) energy systems

- The Energy Management System (EMS) has two - way communication with the smart meters under its control. The EMS of a microgrid receives status and power signals from all of the modules (loads and generating sources).
- The EMS is able to control power flow into and out of the microgrid system from its host local power grid based on variables such as weather forecasts, load forecasts, unit availability, and power sales transactions.
- The MRG systems provide a new paradigm for defining the operation of distributed generation (DG). MRG systems are designed as clusters of loads and micro-sources, operating as a single controllable system. To the local power grid, this cluster becomes a single dispatchable load, which can respond in seconds. The point of interconnection in the smart microgrid is represented by a node where the microgrid is connected to the local power grid.
- This node is referred to as the locational marginal pricing (LMP), where the node price (cost) represents the locational value of energy.

1.10. Smart Micro Grid Renewable energy systems

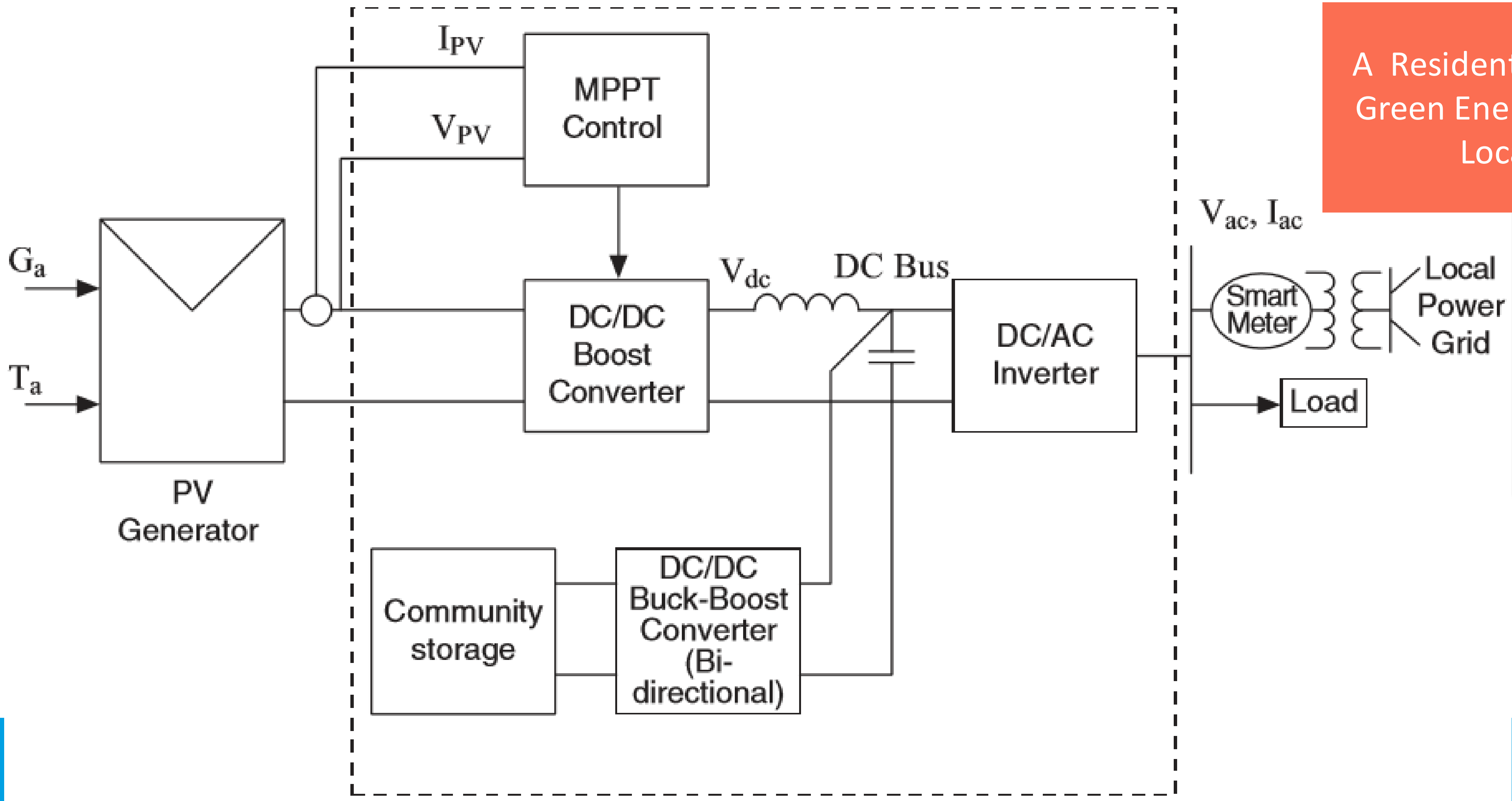


The AC Architecture of a Microgrid Renewable Green Energy (MRG) Distributed Generation (DG) System.

- The architectures shown in previous Figs. are of interest to smart grid technology because they facilitate " plug and play " capabilities. Green energy sources, such as fuel cells, microturbines, or renewable sources, such as PV and wind farms, can be connected to a DC or an AC bus, using uniform interchangeable converters.
- The MRG systems must be able to operate in two modes of operation: ***(1) in synchronized operation with the local power grid system, and (2) in the island mode of operation,*** upon the loss of the power grid system.
- In the island mode the MRG operates as an autonomous microgrid controlling its frequency and bus voltage. When a MRG system is connected to a power grid, the MRG system operates using a master-and slave-control technology. The master referred to is the EMS of the local power grid and the slave is the MRG microgrid. If the MRG system is suddenly separated from its local power grid and MRG stability is maintained, then the slave controller takes over LFC and voltage control.

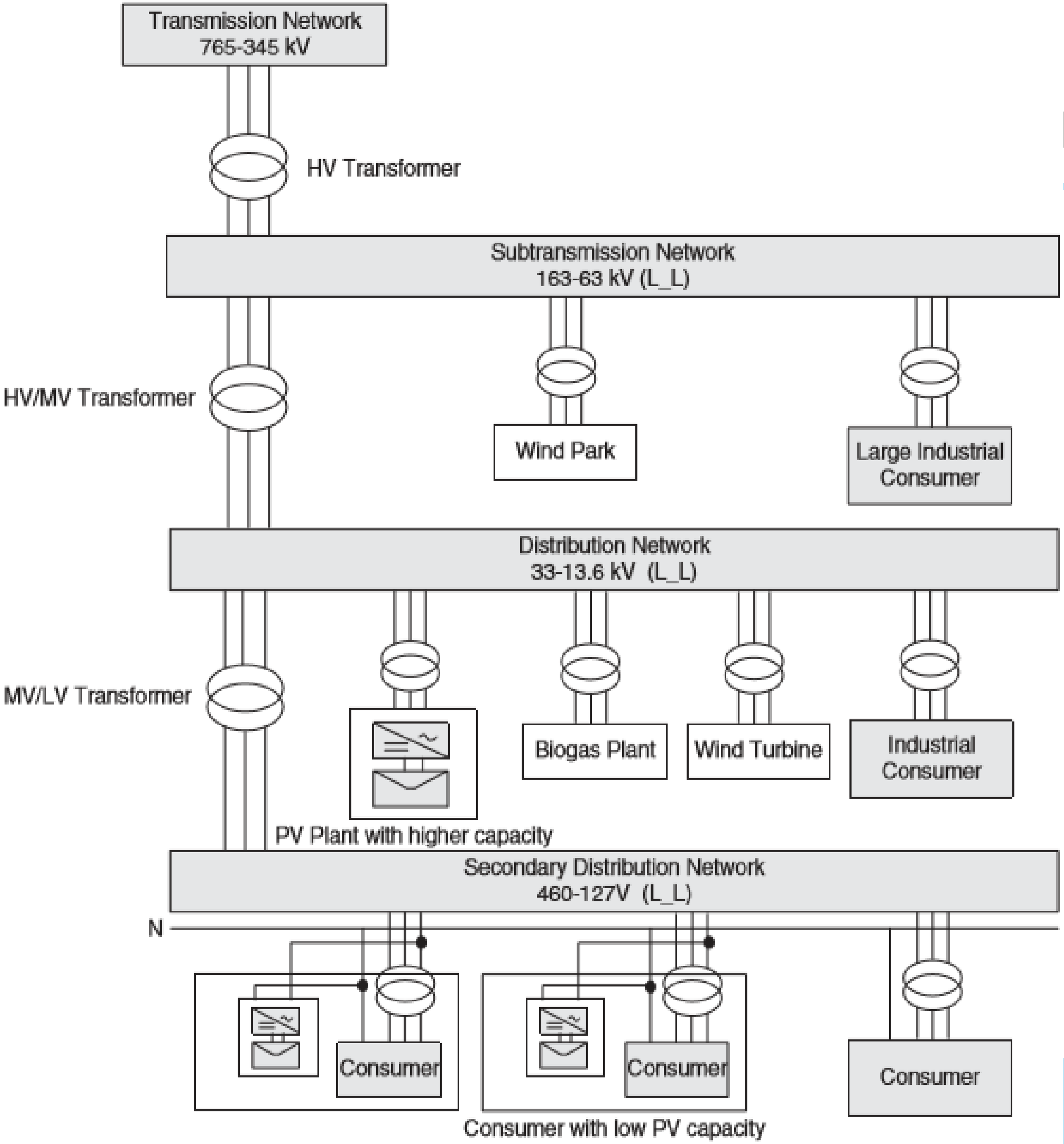
- For MRG systems with high power capacity, there is a purchasing agreement between the power grid and MRG systems, regarding active and reactive power transfer.
- The MRG system can control its loads and accept a "price signal" and/or an "emergency operation signal" from its local power grid to adjust its active and reactive power generation. The MRG system has hardware in place to shed loads in response to a price signal, and it can rotate nonessential loads to keep on critical loads.
- However, because disturbances in a local power grid cannot be predicted with current technology, it is quite possible upon the loss of the local power grid that an MRG system would not be rapidly disconnected from the local power grid; hence, the stability of the MRG systems would not be maintained.

- In Figs of slides 61 and 63, the EMS controls the infinite bus voltage and the system frequency. The slave controller controls the AC bus voltage of the inverter and the inverter current. Therefore, the slave controller of the MRG system inverter must be able to control active and reactive power, at leading or lagging power factor, or operate at the unity power factor.
- In small, renewable energy systems, the inverter is controlled at the unity power factor, and it leaves the voltage control, that is, the reactive power (VArs) control, to the EMS of the local power grid.



A Residential Microgrid Renewable Green Energy (MRG) System with a Local Storage System

- The residential MRG system depicted in previous slide consists of rooftop photovoltaics with a capacity in the range of 5– 25 k VA depending on the available roof surface area.
- A DC/DC boost converter is used to boost the voltage of the DC bus. The maximum power point tracking (MPPT) system is designed to track and operate the PV power generator at the maximum power point.
- The DC/AC inverter converts the DC bus voltage to AC voltage at the operating frequency and rated residential voltage. The MRG system of is connected to the local power grid by stepping up the voltage to the local distribution voltage. The MRG system can also store DC power during the day for use during the night.



Micro Grid Renewable energy systems

Smart Grid with High Penetration of Renewable Energy Sources.

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