EEE 113 Reviewer (?)

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Contents

1 Power Systems

1.1 Power Systems

Electric Power system is a network of electrical components deployed to supply, transfer, and utilize electric power:

- Generation
- Transmission
- Distribution
- Utilization (end use)
- Storage

History of Power Systems in the Philippines

1. La Electricista
   In 1985, power plant in Calle San Sebastian (F. R. Hidalgo St., Manila)
   In comparison to 1882 T. Edison Pear Street
2. Manila Electric railroad and Light Company
   1903, provided light and electric tram (American)
   Bought La Electricista and Compania de los Tranvias de Filipinas
   Most of the facilities destroyed in WW2
   1960s bought by E. Lopez
3. 1972, F. Marcos nationalized the country's electric generation and transmission through NAPOCOR and TRANSCO
4. 2001 RA 9136 Electric Power Industry Reform Act (EPIRA)
   Reconstructing of the power industry to introduce competition
   Change from government to Private Ownership Sectors (Generation, Transmission, Distribution, Supply)

1.2 Basics of Electricity

Electric Charge [Q or q]. Electric charge is one of the basic dimensions of physical measurement. Unit of charge is Coulomb C. $1C = 6.25 \times 10^18$ electrons or protons. Symbol is q or Q.
Electric Field [E]. A charge particle creates an electric field around itself proportional to its charge magnitude, sign (outward if positively charged, inward if negative), and inversely proportional to distance squared.
Voltage [Vor v]. The amount of energy per unit charge to move a charged object from one location to another.

$$V = \frac{W}{Q}$$

In a physical system, voltage is measured across 2 points (terminals or nodes). There is an accumulation of charges in two terminals, giving rise to potential difference or voltage. The potential of A relative to B is written as $V_{AB} = V_A - V_B$.
Conductivity. The property of a material to allow electron flow when a voltage is applied across the material. Electrons in metals are free to travel. Some other conductors are water (with dissolved ions), air (through ionization), and superconductors (temperature at $-200°$

Current [I or i]. The movement of charges. Conventional current is used in analysis (in reality, electrons are the ones moving and electrons move opposite the conventional current.) The unit is the Ampere A the rate at which net charges move past a given area in a specified direction. Defined by magnitude and direction.

$$I = \frac{\Delta Q}{\Delta t} = \frac{\mathrm{dQ}}{\mathrm{dt}}$$

Energy [W or w]. The work expended on forcing electrical charges through an element. Unit is the Joule J.

$$W = QV \implies V = \frac{W}{Q}$$

Power [P or p]. The rate at which energy is being transferred, supplied or consumed. The unit is Watt W.

$$P = \frac{\mathrm{dW}}{\mathrm{dt}}$$
$$P = VI$$

The polarity of voltage and direction of current determines whether power is being supplied or consumed. Power is **consumed** if current enters the terminal of higher voltage (leaves at the lower voltage), and it is **supplied** if current enters the terminal of lower voltage (leaves at the higher voltage).
Value of Electricity. $1kWh \approx 10$ PHP.
1000 W for 1 hour. Equivalent to using charger for 100 hours, $3.6MJ, 860kcal \approx 2850$ cups of adobong baboy, $2.655 \times 10^6 ft - lbf \approx$ lifting a $100lbs$ on top of Mt. Everest.

2 Generation of Electricity

2.1 Electricity Generation

Electricity Production

- Leyden Jars (1745 - 1746) - used to store charges
- 1749, Benjamin Franklin coined the term *battery* - connecting jars resulted to higher discharge
- 1800, Alessandro Volta made the voltaic pile - copper and zinc plates separated by brine - soaked paper disks

Means of Generating Electricity

1. Electrochemical
   Voltaic cell consisting of electrolytes and electrodes. The electrodes do not touch each other but are electrically connected by the electrolyte. A separator allows ion flow but prevents mixing of electrolytes.
2. Photovoltaic Effect
   Transformation of light into electrical energy as in solar cells. Light "excites" electron to higher energy states. In 1839, Edmond Becquerel discovered the pv effect. In 1884, Charles Fritts demonstrated the first solar cell with selenium.
3. Thermoelectric
   Direct conversion of temperature difference to electric voltage. Thermocouples use the Seebeck effect (Volta 1794, Seebeck 1821), while Peltier tiles use the Peltier effect.

4. Electromechanical
   Using a motor to exploit Faraday's Law of Induction. The first electric generator is Faraday's Disk. This is used to generate AC current.
   AC currents follow a sinusoidal function $I = I_{\text{peak}} \cos(\omega t + \alpha_{\text{phase}})$ and $V = V_{\text{peak}} \cos(\omega t + \alpha_{\text{phase}})$. The effective values of current and voltage are the RMS (root - mean - square) values. The RMS is the square root of the mean value of the square of a functions in one period ($1T = 2\pi$ for one sinusoidal functions). For mathematical convenience, set $\alpha = 0$. This gives

$$\begin{aligned}
I_{\text{rms}} &= \sqrt{\frac{1}{T}\int_T I^2} \\
&= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} \left(I_{\text{peak}} \cos(\omega t)\right)^2} \\
&= \sqrt{I_{\text{peak}}^2 \frac{1}{2\pi}\int_0^{2\pi} \cos^2(\omega t)} \\
&= I_{\text{peak}}\sqrt{\frac{1}{2}} \\
I_{\text{rms}} &= \frac{I_{\text{peak}}}{\sqrt{2}} \\
V_{\text{rms}} &= \frac{V_{\text{peak}}}{\sqrt{2}}
\end{aligned}$$

2.2 Sources of Energy

The primary energy sources in the planet are:

- the Sun
- Planetary motion
- Geothermal
- Nuclear reactions on Earth

Energy sources can be classified under

1. Renewable – obtained from the continuous, repetitive flow of energy in the natural environment (solar, hydropower, biomass, geothermal, wind)
2. Nonrenewable – obtained from static/fixed stores of energy that remain bound in nature unless released by human intervention (fossil fuels, coal, nuclear, natural gas)

	Renewable Energy Sources	Nonrenewable Energy Sources
Examples	Solar, wind, hydro, biomass, tidal	Coal, oil, natural gas, nuclear
Source	Natural, local, Environment	Concentrated Stock
Normal State	Current / flow of energy	Static storage of energy
Energy Density	Low	High
Cost (at source)	Free	Increasingly expensive
Reliability	Fluctuating, intermittent, necessitates storage	Relatively steady, controllable
Location of use	Site and society specific	General and International Use
Availability	Exploration of potential and viability necessary before use	Resources has to be explored
Context	Distributed	Centralized
Economics	Most economic for small scale, off - grid	Most economic for large scale
Environmental Effect	Minimal	Harmful
Acceptance	Society specific (may displace minorities)	Acceptance is decreasing (due to side effects)
	Requires efficient energy use and energy conservation	Tendency to waste energy

2.3 AC Generators

1. Thermal Generators - uses heat to turn water into steam and run a turbine

   - Biomass - products that are composed of plants or plant- or animal- derived materials
     - Biogas - biomass that is converted into gas to be used for heat or transportation
     - Biofuel - biomass converted into liquid fuel for transportation
     - Biochar - biomass converted into coal - like product
     - Biopower - burning biomass directly, or converting it to gaseous or liquid fuels that burn more efficiently, to generate electricity
   - Natural gas - naturally occurring hydrocarbon mixtures formed from decomposing plant and animal matter exposed to heat and pressure
   - Geothermal - harnessing heat energy from under the surface of the planet as a result of geological processes or radioactive decay
   - Solar Thermal - concentrated the rays of the sun to a single tube or tower to heat water that drives a generator
   - Ocean Thermal Energy Conversion (OTEC) - use of thermal gradient of the ocean to produce pressure difference that can drive a turbine

2. Nonthermal Generators - replaces steam with other form of prime mover

   - Wind - energy harnessed from movement of air
   - Hydroelectric - use of the movement of water to generate electricity (dams or run-of-river)
   - Wave - use buoys with generators attached to the ocean floor (point or linear absorbers)
   - Tidal - takes advantage of low and high tides to create water head/level difference that can power a turbine-generator system

2.4 DC Generators

1. Solar Photovoltaic - uses photovoltaic effect to generate DC
2. Electrochemical Energy Conversion - uses redox reactions to make electrons move (batteries, fuel cells)

3 Electric Power Transmission and Distribution Networks

3.1 Generation to T & D

On Generation Systems Resources are site - specific and geographically dispersed (indigenous sources). These have fuel delivery constrains and faces power plant requirements: cooling medium, space requirements, natural and man-made storage (e.g. pumped-storage hydroelectric power plant)
Technical Justification for Expansion and Interconnection

1. Economies of Scale - it is less expensive to build and operate one large generator that several small ones
2. Improvement of Load Factor - assets should be utilized all the time. Diversity in utilization improves load factor
$$\text{load factor} = \frac{\text{average load}}{\text{peak load}}$$
3. Enhancement of reliability by pooling generation reserves - it is good to have a variety of backup generators

Structural Features

1. Typical System Diagram - shows transmission and distribution
   - Generator ($115 - 765kV$) to Transmission
   - Switching Station to Very Large Consumers
   - High Voltage (HV) Substation ($69 - 138kV$) to Subtransmission or Large/Medium Consumers or Network
   - Distribution Substations ($4 - 34.5kV$)
   - Distribution Transformers
   - Residential Consumers ($240/120V$)
2. AC vs DC
3. High voltage vs Low voltage (use of transformers)
4. Three phase - from the generation, balancing loads
5. Topology - Loop vs Radial

Distribution System Loss - Power loss in the distribution of energy. Power loss can be

1. Technical loss - inherent in the delivery of power; dictated by the physical characteristics of equipment and conductors.
   - conductor loss or load loss $= I^2R$

- core loss or no-load loss

2. Non-technical loss
   - Direct theft and illegal connection
   - Meter tampering
   - Billing irregularity

3.2 Electric Power: Quantitative Basics

Current. Flow rate of charge. Current through a conductor is analogous to flow of fluid in a conduit. Both magnitude and direction are specified.
Kirchhoff's Current Law (KCL) also Kirchhoff's Junction Rule. Currents entering and leaving any node (or junction) must add up to zero.

$$\sum I = 0$$

Series Connection. Loads are said to be in series if the SAME current flow through both of them.

$$I_1 = I_2 = ... = I_n$$

Magnetic Field. Currents produce magnetic field that follow the right-hand-rule: the eletromagnetic field.
Voltage. The work done per unit charge to move a charged object in an electric field. Voltage is location specific, either with respect to a reference (the zero potential or *ground*) or with respect to each other (potential difference).
Kirchhoff's Voltage Law (KVL) or Kirchhoff's Loop Rule. About any closed loop, the algebraic sub of voltages is equal to zero.

$$\sum V = 0$$

Parallel Connection. Loads are said to be in parallel if they are connected to the same pair of nodes, and thus equal potential difference across them.

$$V_1 = V_2 = ... = V_n$$

Ohm's Law. For conductors, the voltage across the current is proportional to the current flowing through it. The constant of proportionality is the resistance of the conductor.

$$V \propto I \implies V = IR$$

Resistance [R]. Ability of device to resist or impede current. Unit is Ohm Ω. The resistance is affected by the type of material (its resistivity ρ), the length (longer material has higher resistance), cross-sectional area (larger area has lower resistance), and temperature (higher temperature results to higher resistance). Under normal conditions,

$$R = \frac{\rho L}{A}$$

3.3 AC or DC Transmission

- AC allows voltage transformation (through transformers)
- HVDC is also available (e.g. Naga - Leyte 350 kV HVDC link)
  - DC network has no reactance involved (inductance for overhead, capacitance for undersea)
  - utilizes two conductors (conductor - pair), instead of three wires
  - developments in power electronics has made this possible
  - stability limit (caused by reactance) is eliminated
- Low voltage DC networks is becoming more common (DC generation and DC load)

3.3.1 Direct Current

Electric Energy and Power. Power is computed as product of voltage and current. Work done is commonly described as electric energy.

$$\begin{aligned} P &= V \times I \\ P &= \frac{W}{Q} \times \frac{Q}{t} \\ W &= P \times t \end{aligned}$$

For a resistor, we can use Ohm's Law to write power in terms of the resistance and current or voltage.

$$P = VI = \frac{V^2}{R} = I^2 R$$

3.3.2 Alternating Current

High Voltage or Low Voltage. Transformers allow AC voltage to be scaled up or down. Keeping P to be constant, I is reduced as V is increased. Thus, the power loss $P_{\text{loss}} = I^2 R$ is reduced. Also, the voltage drop along the transmission line is reduced $\Delta V = I(R + jX)$. X is the *reactance* of the load, and j is the imaginary number $\sqrt{-1}$ (to avoid confusion with the current i. At higher voltage, more insulation is needed, since insulators have voltage breakdown characteristics.

Transformers. These are cores that allow magnetic flux to "flow". The primary winding (N_1, I_1, V_1) is connected to the source, and the secondary winding (N_2, I_2, V_2) is connected to the load. N is the number of turns of the wire. In an *ideal* transformer, there is no power loss. The relations of N, I, and V are:

$$\begin{aligned} V_1 I_1 &= V_2 I_2 \\ \frac{V_1}{V_2} &= \frac{N_1}{N_2} \\ \frac{I_1}{I_2} &= \frac{N_2}{N_1} \end{aligned}$$

Voltages in the Philippines

- Generation: $4.16kV, 6.6kV, 13.2kV, 13.8kV$, others

- Transmission: $230kV$ or $500kV$; also $350kV$ HDVC
- Subtransmission: $115kV$ or $69kV$
- Primary Distribution: $13.2kV$(electric cooperatives), $13.8kV, 23kV, 34.5kV$(Meralco)
- Secondary Distribution: $240V$
- EHV: [500 kV, above)
- HV: [100 kV, 500 kV)
- MV: [1 kV, 100 kV)
- LV: (below, 1 kV)

Alternating Current Systems

The sinusoidal voltage in the power outlets is 60 cycles per second or $60Hz$. Compared to Dc system, AC voltage and current both varies in a sinusoidal manner. The parameters of AC signals are:

- Frequency = $60Hz$
- Magnitude
- Angle or Phase Shift

Lag or Lead?

The one leading is the one who arrives to a maximum before the other. In an *inductor* the voltage leads its current by one-fourth of a period 90°. In a *capacitor*, the current leads its voltage by 90°.

Transforming Sinusoid to a Phasor

$$\begin{aligned} V(t) &= \vec{V} \\ V_{\text{max}}\cos(\omega t + \alpha) &= V_{\text{rms}}\theta = V_{\text{re}} + jV_{\text{im}} \end{aligned}$$

It is more convenient to represent any time sinusoid with a phasor. The magnitude of the phasor is the RMS value of the sinusoid. The phase angle is the phase shift with respect to a reference. A phasor has real and imaginary components.

Ohm's Law for AC system

With voltage and current represented as phasors, the constant ratio is the *impedance* (Z), which is a complex number.

$$\frac{V}{I} = Z = R + jX$$

The real part is the resistance R and the imaginary part is the reactance X. The reactance of a resistor is 0, while the reactances of an inductor (L) and a capacitor (C) are given by:

$$\begin{aligned} X_L &= j\omega L \\ X_C &= -\frac{1}{j\omega C} \\ X &= X_L + X_C = j\omega L - \frac{1}{j\omega C} \end{aligned}$$

	Resistive	Inductive	Capacitive
Reactance	0	Positive ($j\omega L$)	Negative $\left(-\frac{1}{j\omega C}\right)$
Phase Angle	0	Positive $\left(\tan^{-1}\left(\frac{\mathrm{X_L}}{\mathrm{R}}\right)\right)$	Negative $\left(\tan^{-1}\left(\frac{\mathrm{X_C}}{\mathrm{R}}\right)\right)$
Which leads?	In phase	Voltage	Current
Which lags?	In phase	Current	Voltage
Reactive power	0	Absorbed	Delivered
Power factor	1	Lag [0, 1)	Lead [0, 1)

Electric Power The power in an AC system is complex, as the current and voltage are both represented as phasors.

$$\begin{aligned} S &= VI^* \\ S &= P + jQ \end{aligned}$$

I^* is the conjugate of I, it is used to find the phase difference of V and I.
S is the *apparent power* (volt-ampere, VA); P is the real component and is the *Real Power* (watts, W); Q is the imaginary component and is the *Reactive Power* (volt-ampere reactive, VAR)
Let the phase angle be ϕ. The representation of impedance is a right triangle in the complex plane, with Z being the hypotenuse. The power triangle is similar to the impedance triangle, with hypotenuse S. By some trigonometry

$$\begin{aligned} P &= VI\cos\phi \\ Q &= VI\sin\phi \end{aligned}$$

The value $\cos\phi$ is the *power factor* which is the ratio of real power to apparent power.

If the resistance and reactance are in **series**, with current I,

$$\begin{aligned} Z &= R + jX \\ S &= I^2R + jI^2X \end{aligned}$$

If the resistance and reactance are in **parallel**, with voltage V,

$$\begin{aligned} \frac{1}{Z} &= \frac{1}{R} + j\frac{1}{X} \\ S &= \frac{V^2}{R} + j\frac{V^2}{X} \end{aligned}$$

3.4 Three-phase System

AC generators have been designed to produce three-phase voltages. A constant torque is produced with 3-phase or higher configuration. It uses less wires, as single phase uses two (supply line + return) while three-phase uses 3 to 4 (3 supply lines + neutral). A balanced three-phase system is drawn as a single-line diagram, and analyzed as a single-phase equivalent. In three-phase system, $I_A(t) + I_B(t) + I_C(t) = 0$ always.

3.5 Topology

1. Radial

   - lines branch out from a single source

- currents (and power) flow radially outward
- power flows downstream
- smaller equipment sizes at downstream locations

2. Grid or Network Configuration

    - interconnections are available across multiple sources and multiple sinks
    - various paths for current (and power) to flow
    - redundancy is available; $N-1$ is even required

3.6 Operating a Power Network

Electricity is generated as it is demanded. We have to balance real power (between generators and loads) and reactive power (between inductors and capacitors). Very little storate is available: inertia of machines; storage devices.

3.6.1 Time Scales

1. Cycle
   A cycle is too fast for human intervention.

    - Generation
        - natural feedback available in generators – developed torque to bring the machine back to the right (synchronous) speed
        - built-in control in power plants – when the frequency varies, fuel intake is automatically controlled.
    - Protection: If a short-circuit occurs, circuit breakers or fuses shall respond.

2. Real - time operation
   Where humans perceive and analyze information, make decision, and take actions in a few minutes.

    - This includes generator procedures such as start-up, synchronization, or shutdown.
    - The system operator's actual dispatch compared to forecasted demand:
        - load variation based on consumer behavior
        - hourly forecast and dispatch
        - generator output deviating from schedule
        - line losses.
    - Loads may be shed
    - Line reconfiguration may be done

3. Scheduling
   Which generation units to operate when and at what power level (currently on an hourly-basis).

    - Mostly economic considerations via an electricity market (bid-based)
    - System Operator will finalize the schedule to ensure network security
        - No line or transformer is overloaded
        - Response to emergency

- Unit Commitment (which plants to operate?) plus Economic Dispatch (at what power level?
- Reserves (e.g. spinning reserve) are needed, and are contracted in advance

4 Pricing of Electricity in the Philippines

4.1 Philippine Electricity Sector

There are two eras of Philippine Electricity: pre-EPIRA and post-EPIRA. [Electric Power Industry Reform Act of 2001 (RA 9136)]

1. before EPIRA 2001
   - Generation: COntrolled bythe National Power COrporation (NAPOCOR) and Independent Power Producers (IPP) - with wholesale contracts with NPC and some distribution companies
   - Transmission: National Power Corporation
   - Distribution and Supply: Private Distribution Utilities; Electric Cooperatives; NPC
2. after EPIRA 2001
   - Generation: has to go through Wholesale Electricity Spot Market (WESM); privatized to encourage competition
   - Transmission: regulated and privatized; with System Operator franchise and with open access
   - Distribution: regulated, privately-owned, with open access
   - Retail/Supply: competitive with Retail Competition and Open Acce (RCOA)

Some important agencies:

DOE	Department of Energy	Supervises electricity industry
ERC	Energy Regulatory Commission	Quasi-judicial regulatory body
NPC	National Power Corporation	
NPC - SPUG	Special Power Utilities Group	Performs missionary electrification
PSALM	Power Sector Assets and Liabilities Management Corporation	owns all existing NPC generation assets, liabilities, IPP contracts, real estate, and other disposable assets
Transco	National Transmission Corporation	Assume all transmission function of NPC; owner of transmission assets
NGCP	National Grid Corporation of the Philippines	Concessionaire of transmission network for 25 years
WESM	Wholesale Electricity Spot Market	Market where all generators must bid their electricity price
PEMC	Philippine Electricity Market Corporation	Corporation managing WESM

IEMOP	Independent Market Operator of the Philippines	Operates WESM
NEA	National Electrification Administration	Strengthen capability and viability of electric cooperatives
MERALCO	Manila Electric Corporation	Transmits and distributes electricity in Metro Manila and surrounding regiosn
EC	Electric Cooperatives	Transmits and distributes electricity in the provinces
RES	Retail Electricity Supplier	Sells, brokers, markets, or aggregates electricity to end - users

4.2 Electric Bill

Components of the Electric Bill

1. **Generation Charge**. paid to IPPS and NPC
2. **Transmission Charge**. paid to Transmission Network Operator (NGCP); fee of delivery from generators
3. **System Loss Charge**. RA 7832, this is allowed. 6.5% for private Distribution Utility; 12% for Electric Cooperative
4. **Distribution Charge**. building, operating, and maintaining the distribution system of DU's
5. **Metering Charge**. reading, operating, and maintaining power metering facilities
6. **Supply Charge**. rendering of service, such as billing, collection, customer assistance, and associated services.
7. **Subsidies**. *Lifeline Subsidy* to those who can't pay; and *Senior Citizen Discount* to the elderly.
8. **Government Tax**. *Local Franchise Tax* is levied by provinces and cities for businesses enjoying a franchise; and *Value Added Tax.*
9. **Universal Charges**. remitted to PSALM, for missionary electrification and environmental charges and stranded cost
10. **FIT-All**(Feed - in - Tariff Allowance) for renewable resources; rates: Wind (8.53 - 7.40) and Solar (9.68 to 8.69)

4.3 Wholesale Electricity Spot Market

Market Design. Has hourly and daily trading mechanism. Generator must submit offers to be scheduled in the power system *(Gross Pool)*. Generating Trading Participants must have Energy Offer (Price and Quantity). The price offer that reaches the demand cutoff dictates the System Marginal Price (SMP).
Locational Marginal Pricing (LMP) = Generation Price (SMP) + Cost of Losses + Transmission Congestion Cost

Cost of Electricity

- Generation Charge is the largest component. About 85% on bilateral contract vs 15% on spot market; competitive supply procurement has been introduced recently
- Premium paid for Renewable Energy resources
- Distribution Charge is about thrice Transmission Charge. Retail/Supply has been distinguished from the distribution business; competition in retail is yet to happen
- Government taxes vs. subsidies. In many ASEAN countries, electricity is subsidized by the government; stranded cost are paid by the customers
- Transparency in cost is paramount. System loss charge for distribution but none for transmission

5 Introduction to Smart Grid

5.1 Challenges to the Existing Electric Power System

1. Depleting fossil fuel resources and environmental concerns
2. Increasing demand over larger geographical area
3. Digital economy requires higher supply reliability and availability (more computing power = more energy requirement)
4. Power flows were not anticipated in the original design of the network; due to deregulation, renewable energy (evolves very fast 2010 - 1 MW solar, 2015 - 150 MW), and distributed energy resources (solar can be used in household, now customers can now sell electricity to distributors)
5. Terrorist attack to physical and cyber assets, and cyberphysical terrorism
6. Aging network

Techno-economic Solutions

1. Range of technology that has been demonstrated or widely perceived to promote sustainable energy service consumption
   - Distributed energy resources
   - Energy efficiency
   - Renewable energy
   - Advanced communication and control of electricity infrastructure

   These 4 are under Smart Grid
2. Economic solutions like competitive pricing of sustainable energy technology and demand response programs (influencing the demand side, like palit-ilaw and labeling of energy efficiency; time of use (TOU) rates is effective to commercial and industrial) [already practiced]

Distributed Energy Resources
Distributed energy resources are *small* and *geographically-dispersed* resources and practices *co-located* or *near* the end-users that can support the existing electricity system infrastructure in providing energy services

Traditional Utility: big generation and transmission (Centralized Utility) Modern Utility: (Microgrids) has substations to get emergency power; however units can also stand on their own Resilient electricity grid - should be ready for disasters

5.2 Smart Grids

- US Department of Energy. “Smart grid” generally refers to a class of technology people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. These systems are made possible by two-way communication technology and computer processing that has been used for decades in other industries.

- Institute of Electrical and Electronics Engineers (IEEE). The smart grid has come to describe a next-generation electrical power system that is typified by the increased use of communications and information technology in the generation, delivery and consumption of electrical energy.

- Wikipedia. A smart grid is a digitally enabled electrical grid that gathers, distributes, and acts on information about the behavior of all participants (suppliers and consumers) in order to improve the efficiency, importance, reliability, economics, and sustainability of electricity services.

Commonality: power system (grid), computing (automation), communication (information). Smart grids as integration of two infrastructures: Electrical + Information.

Technologies that will drive the smart grid

1. **Integrated communications**. connecting components to open architecture for real-time information and control, allowing every part of the grid to both ‘talk’ and ‘listen’

2. **Sensing and measurement technologies**. to support faster and more accurate response such as remote monitoring, time-of-use pricing (transactive energy) and demand-side management (V2G - Vehicle to Grid)

3. **Advanced components**. to apply the latest research in superconductivity, storage, power electronics, and diagnostics

4. **Advanced control methods**. to monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event

5. **Improved interfaces and decision support**. to amplify human decision-making, transforming grid operators and managers quite literally into visionaries when it come to seeing into their systems

5.2.1 Smart Homes [Nanogrid]

Residential Buildings that actively participate in balancing load and generation; there is on-site generating resources, energy storage, energy efficiency and conservation (home automation, dynamic pricing, demand response)

1. Energy star appliance

2. Photovoltaic panels
3. Dimmable fluorescent/CFL lighting
4. Utility demand side management control
5. Digital net meter
6. Plug-in hybrid electric vehicles
7. Prepaid power
8. Electronic service panel (has the circuit breakers)

5.2.2 Microgrid

Interconnection of small, modular generation to low voltage distribution systems can form a new type of power system.
MicroGrids can be operated connected to the main power network or islanded, similar to power systems of physical islands, in a controlled, coordinated way.

5.2.3 Distribution Management System

Manages MicroGrids.
Basic DMS Application: Advanced Display Advanced DMS Application: Network Modeling [Distribution System Model]

5.2.4 Energy Management System: Transmission

- Advanced grid operator visualization system
- Decision support systems
- Control system cyber security

Transmission facilities:

- Flexible AC transmission ssytem (FACTS) devices
- High voltage DC transmission

5.3 Advanced Metering Infrastructure

Smart meters as foundation of the smart grid with the following features:

- 2-way communication with the utility (reliable and secure)
- Recording of usage intervals (15 or 60 mins)
- Recording of power quality information such as voltages and outages
- Sending of data to utility at least daily
- Internal switch for disconnection
- Home Area Network interface

Benefits of AMI

- Accurate meter reading and improved billing
- Key facilitator for demand management programs (real-time pricing, direct load control, etc.)
- Outage detection data that can be integrated with outage management systems
- Tamper and theft detection, and notification
- More customer information for the utility: real-time and fine-grained measurements that may be used operational decision making, planning and maintenance
- The AMI link may provide other functions: e.g. internet access for the customer, and communications and distribution automation for the utility

Disadvantages of AMI

- Loss of privacy because of more detailed energy usage information
- Potential for monitoring and interception of customer data by unauthorized third parties
- Increased security risks from network or remote access