EVs, Renewable Energy and Smart Grid

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Lecture 6-7-8

Introduction

- Society depends on secure and reliable supply of electrical energy
- Electrical energy comes to the load from sources through a network/grid.
- Loads - light, fan, refrigerator, computer, washing machine, electric vehicle, different other machines in mills/factories/hospitals
- How electricity is generated?

Introduction

- Generators convert mechanical energy to electrical energy
- mechanical energy? - potential energy/kinetic energy
- Thermal power plant, Hydro electric Power plant, Nuclear Power Plant - Conventional
- New- Wind, Solar, Biomass, Geothermal etc.

Clean Energy

- Clean/Sustainable Energy? -Comes from sources that can fulfill our current energy needs without compromising future generations
- Renewable Energy? -Comes from sources that naturally renew themselves at a rate that allows us to meet our energy needs
- Why do we need Renewable Energy?

Wind turbines and a large solar panel in Palm Springs, California

Why is Renewable Energy Integration important for Power Grid ?

Motivation

- Goal of the Power System Operator - to meet the load demand providing energy from generators at low cost
- Load Demand - Residential, Office, factory etc
- Should we think of environment/climate?
- Low cost energy- mostly generated from coal

Emission vs Temeparature Rise

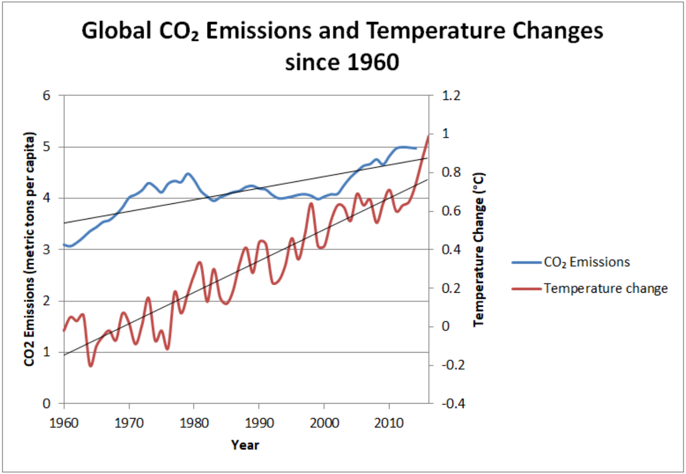


Figure: Correlation Between CO_2 Emission and Temperature Rise

* Source: The magazine 'The Spartan Speaks', November 2017

Cost of Wind Generation

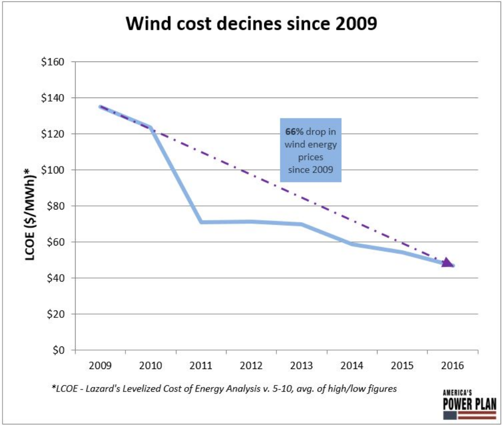


Figure: Wind Generation is getting cheaper

Cost of Solar Generation

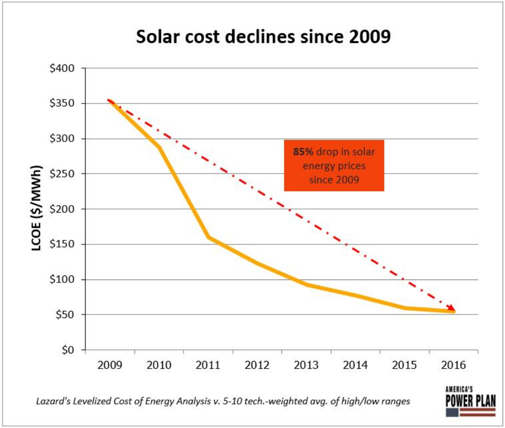


Figure: Solar Generation is getting cheaper

Challenges of Renewable Integration

- Issues- Concern over carbon emission, Climate Change, Sustainability
- We need large scale integration of renewables in the electrical grid
- Challenges- Renewable sources are variable i.e.,
  1. uncertain,
  2. intermittent
  3. non-dispatchable

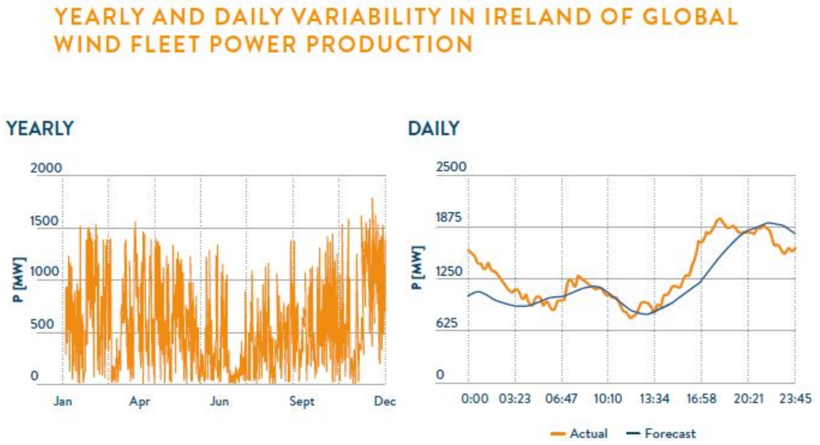


Figure: Variability of Renewable Resources

*Source: World Energy Council, 2016

Potential Solutions

- Energy Storage
- Demand Response
- Aggregation of Resources
- Electrification of transportation
- Improving Power System Operation Methods

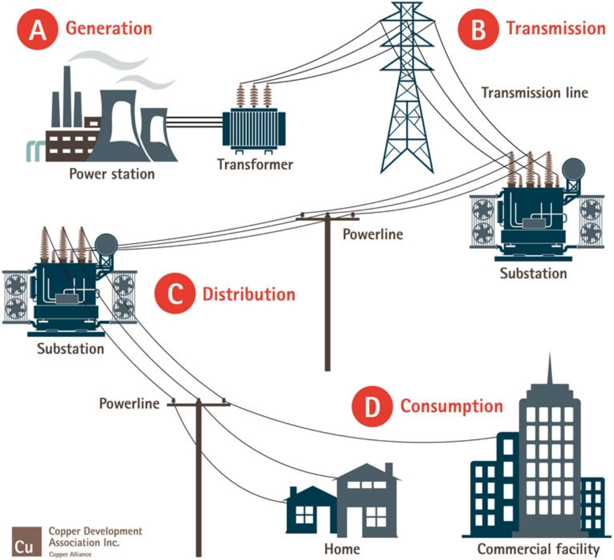
Potential Solutions

- Energy Storage can absorb the variability and result in a controllable output, expensive in grid scale
- Demand Response (DR)- Consumers actively participate in supply-demand balancing of power grid
- Price-based DR, Incentive-based DR

Potential Solutions

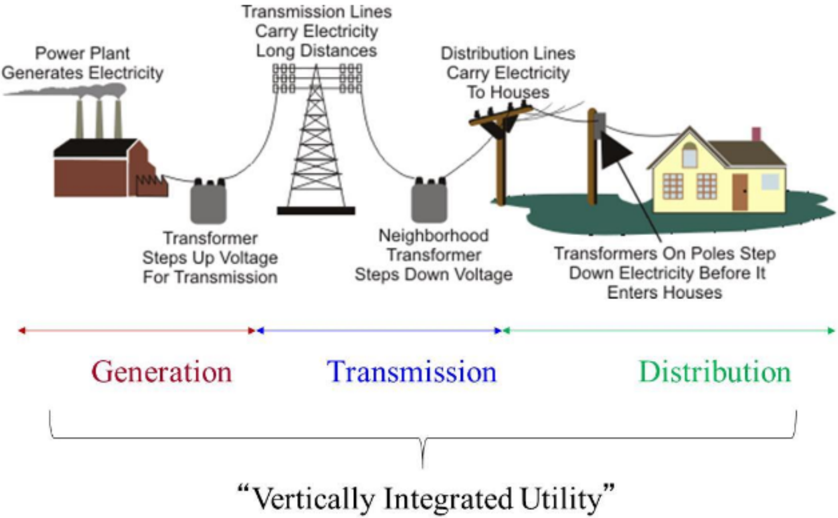
- Power system operator can penalize a plant for deviations from commitments.
- Multiple plants can form coalitions to aggregate output and reduce the penalty.
- Electric Vehicles- charging and discharging in line with available supply
- Introducing dynamics in power system planning methods
- Introducing optimization in power system control methods

Power Grid

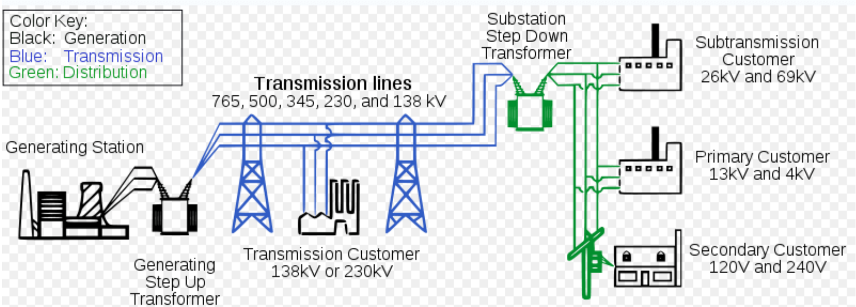


A Generation
B Transmission
Transmission line
Power station
Transformer
Powerline
Substation
C Distribution
Substation
Powerline
D Consumption
Copper Development Association Inc.
Copper Alliance
Home
Commercial facility

Power Grid

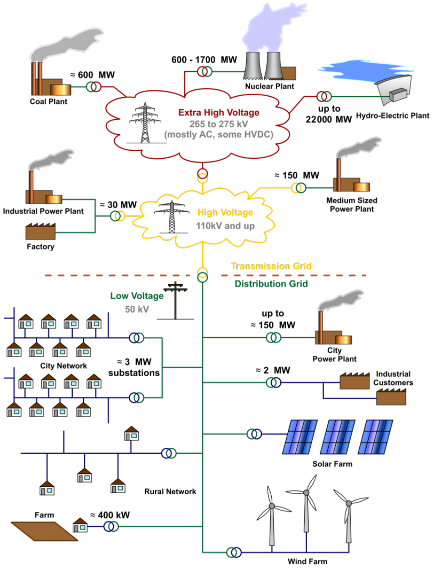

Transmission Lines
Carry Electricity
Long Distances
Power Plant
Generates Electricity
Distribution Lines
Carry Electricity
To Houses
Transformer
Steps Up Voltage
For Transmission
Neighborhood
Transformer
Steps Down Voltage
Transformers On Poles Step
Down Electricity Before It
Enters Houses
Generation
Transmission
Distribution
"Vertically Integrated Utility"

Power Grid



Color Key:
Black: Generation
Blue: Transmission
Green: Distribution
Transmission lines
765, 500, 345, 230, and 138 kV
Substation
Step Down
Transformer
Subtransmission
Customer
26kV and 69kV
Generating Station
Primary Customer
13kV and 4kV
Secondary Customer
120V and 240V
Generating
Step Up
Transformer
Transmission Customer
138kV or 230kV

Power Grid



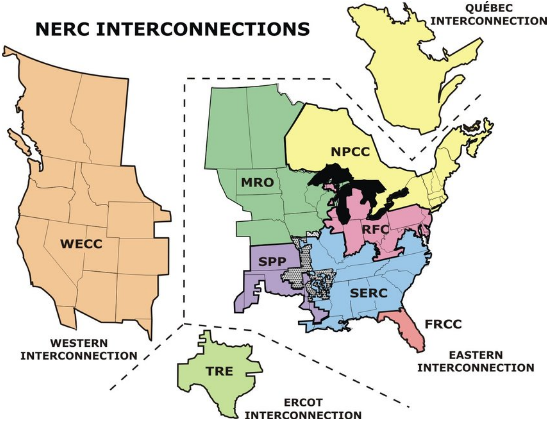
≈ 600 MW
Coal Plant
600 - 1700 MW
Nuclear Plant
up to
22000 MW
Hydro-Electric Plant
Extra High Voltage
265 to 275 kV
(mostly AC, some HVDC)
≈ 150 MW
Medium Sized
Power Plant
Industrial Power Plant
≈ 30 MW
Factory
High Voltage
110kV and up
Transmission Grid
Distribution Grid
Low Voltage
50 kV
up to
≈ 150 MW
City
Power Plant
City Network
≈ 3 MW
substations
≈ 2 MW
Industrial
Customers
Solar Farm
Rural Network
Farm
≈ 400 kW
Wind Farm

Power System

- Existing power system- two centuries old
- Vertical structure consisting of centralized large generation, transmission, and distribution system along with necessary monitoring and control
- Generation, Transmission, Distribution
- System operator- monitors and controls safety and security of the power system in real time
- SCADA- Supervisory Control and Data Acquision System

System Operator

North American Grid



System Operators

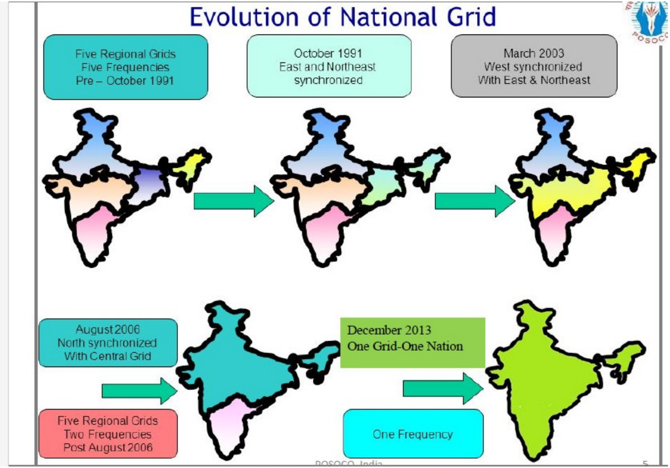
Independent System Operators (ISO)

- Alberta Electric System Operator (AESO, an ISO)
- California Independent System Operator (California ISO)
- Electric Reliability Council of Texas (ERCOT, an ISO)
- Ontario's Independent Electricity System Operator (IESO, an ISO)
- ISO New England (ISO-NE, an RTO)
- Midwest Independent Transmission System Operator (Midwest ISO, an RTO)
- New York Independent System Operator (NYISO)
- PJM Interconnection (PJM, an RTO)
- Southwest Power Pool (SPP, an RTO)
- New Brunswick System Operator (NBSO, an ISO)

Indian Grid

Source: U.S. Energy Information Administration

Indian Grid


Evolution of National Grid
Five Regional Grids
Five Frequencies
Pre – October 1991
October 1991
East and Northeast
synchronized
March 2003
West synchronized
With East & Northeast
August 2006
North synchronized
With Central Grid
Five Regional Grids
Two Frequencies
Post August 2006
December 2013
One Grid-One Nation
One Frequency
POSOCO India
5

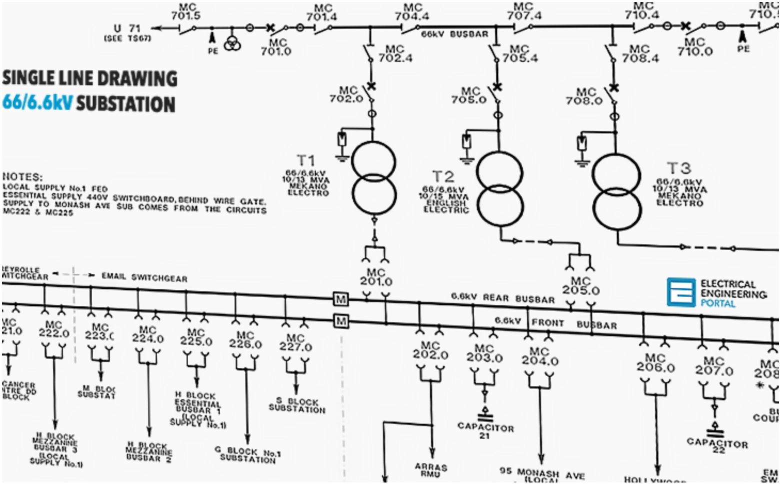
Substation

Components of Substation

Components of Substation

Transmission Lines, tower

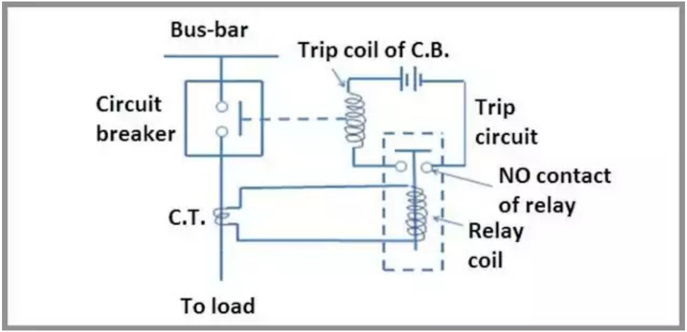
Single Line Diagram



Power System

- Transmission network is in general a mesh network
- Power Grid Protection- relay+circuit breaker
- (n-1) Security - The basic principle of n-1 security in network planning states that if a component – e.g. a transformer or circuit – fail or be shut down in a network operating at the maximum forecast levels of transmission and supply, the network security must still be guaranteed.

Relay and Circuit Breaker



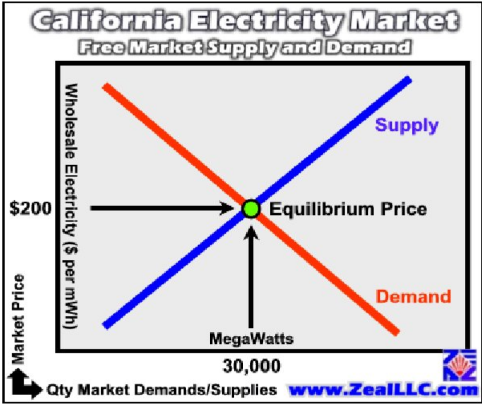
Power Systems Operations

The prevailing practice involves two parts:

- an offline economic dispatch (ED) problem, in which the system operator minimizes the cost of generation based on load forecasts while enforcing various operational constraints,
- a real-time automatic generation control (AGC), - proportional-integral control-based AGC adjusts generator outputs around their ED setpoints based on deviations in frequency

Electricity Markets

- An electricity market, also power exchange or PX, is a system enabling purchases, through bids to buy; through offers to sell. Bids and offers use supply and demand principles to set the price.



Electricity Markets

In the basic ED, a central operator solves this problem with full knowledge of the economic and technical data of the generating units and demand. Within a market environment, this basic ED problem can be solved alternatively as follows :

- A market operator broadcasts trial market-clearing prices.
- Considering these prices, the producers determine their optimal productions and submit them to the market operator.
- For every hour of the market horizon, the market operator computes the power mismatch.

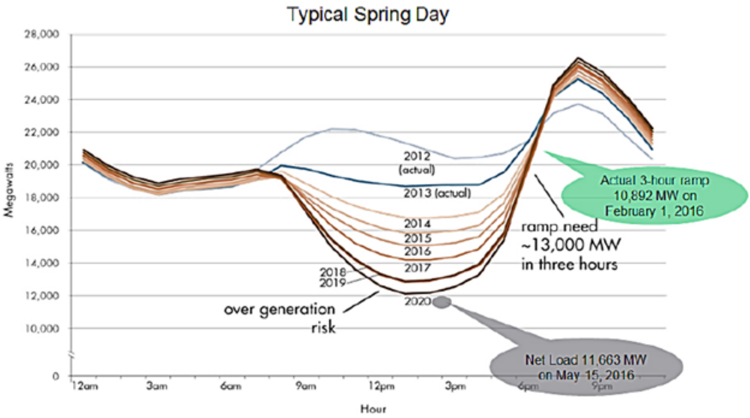
If mismatches are small enough, the procedure concludes. If not, the market operator modifies trial hourly prices proportionally to the respective mismatches, and the procedure continues from 1.

Active and Reactive Power Balance

- **Frequency** of an electric system depends on the **active power balance**. If a generation-load active power imbalance occurs, the frequency will either increase or decrease, thus moving away from its nominal operating value.
- **Voltages** at all the nodes depend on **reactive power balance** in power grid.

Typical Indian Load Curve

Duck Curve of California



New Components

- Conventional distribution system is radial
- Future distribution system will be mesh network as well
- Distributed generation, bi-directional flow, prosumers, demand response, storage
- Microgrid -independent small energy system to serve a specific area
- ICT (Information and Communication Technology)

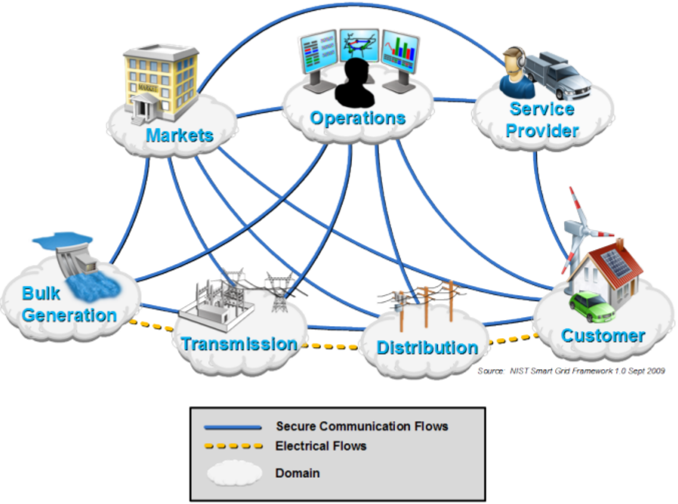
Phasor Measurement Unit

- A phasor measurement unit (PMU) is a device used to estimate the magnitude and phase angle of an electrical phasor quantity (such as voltage or current) in the electricity grid using a common time source for synchronization.
- These measurement data are the basis of wide area monitoring system

New Components

- Smart Meters, Advanced Metering infrastructure (AMI)
- Big Data, Cyber security
- Smart Grid Communication
- Home Energy Management
- Net Metering

Architecture1



Architecture2

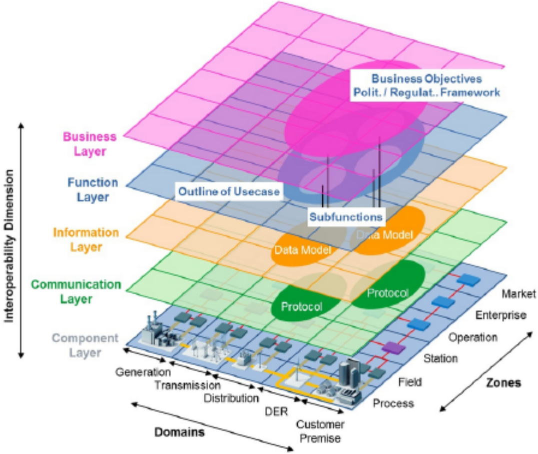
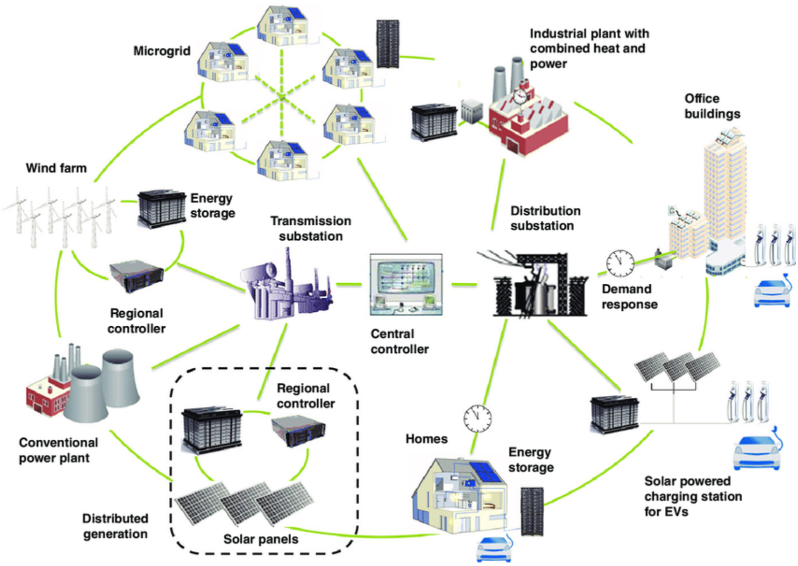


Figure 1. Smart grid architecture model (SGAM) with interoperability layers.

Vision for Smart Grid



Conventional/Existing Grid

- Electromechanical
- One-way communication
- Centralized generation
- Few Sensors
- Manual monitoring
- Manual restoration
- Failures and blackouts
- Limited control
- Passive consumers

Smart Grid

- Digital
- Two-way communication
- Distributed generation
- Sensors throughout
- Self monitoring
- Self-healing
- Pervasive control
- Active consumers