# Microgrid 101


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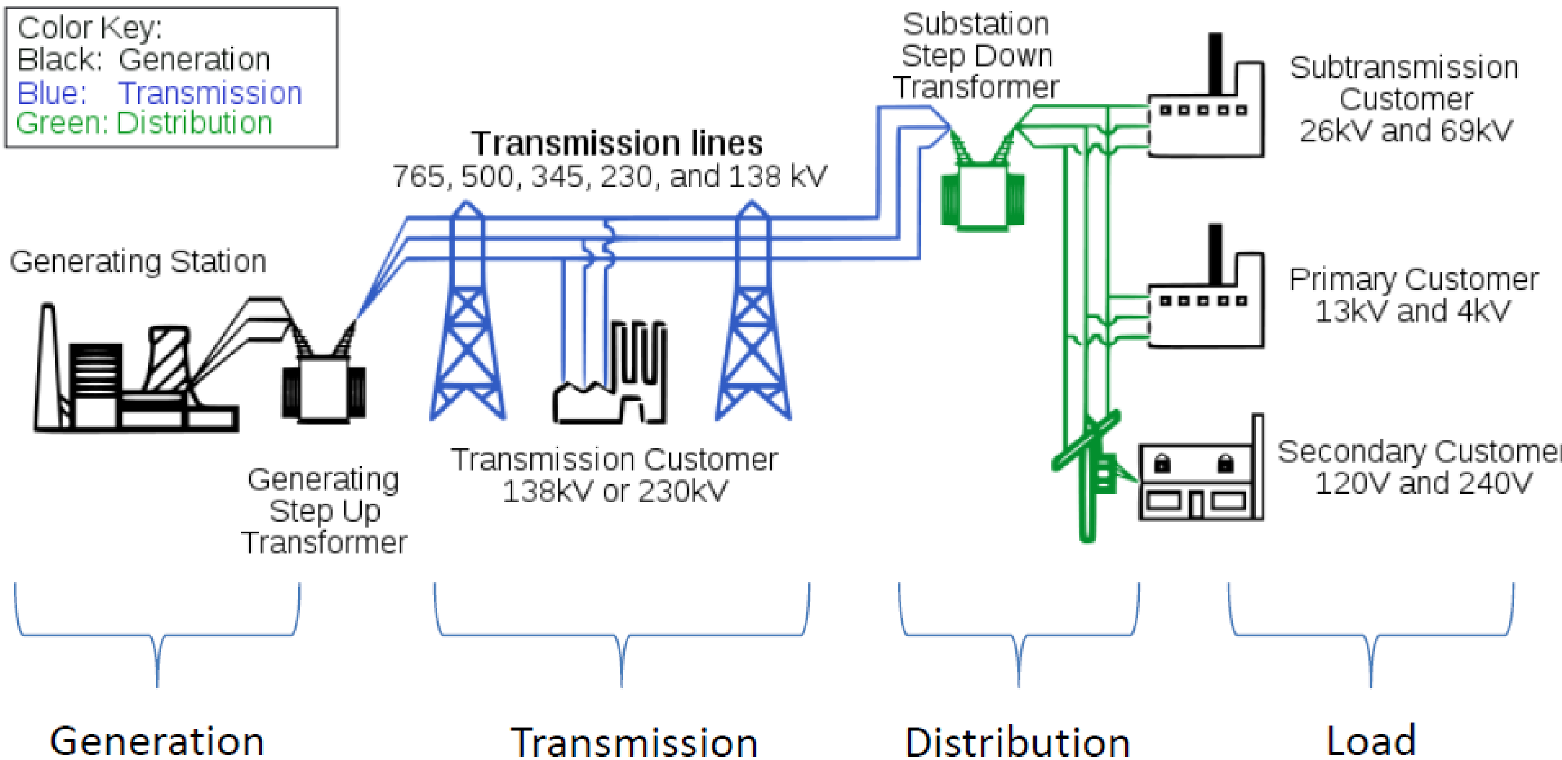
# Outlines

- **Power Systems**
- **Smart Grid**
- **Microgrid**

# Power Systems



# Power Systems

- The Four Main Elements in Power Systems:

  Power Generation

  Power Transmission

  Power Distribution

  Power Consumption

# Power Systems

- Power Generation:
  - Different Types:
    - Traditional
    - Renewable
  - Capacity, Cost, Carbon Emission
  - Step-up Transformers

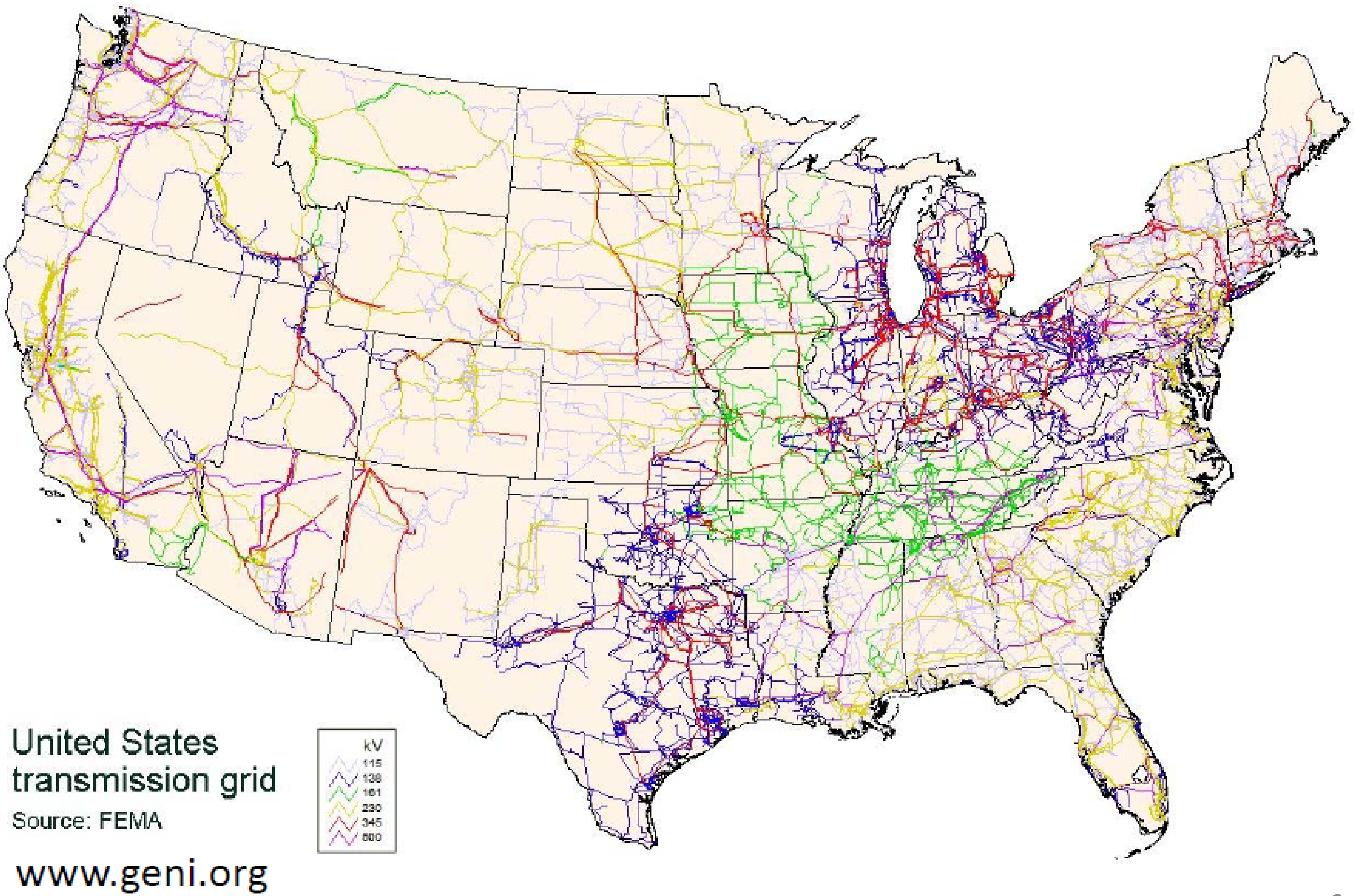
- Installed U.S. generation capacity is about 1000 GW ( about 3 kW per person)

# Power Systems

- Power Transmission:
    - High Voltage (HV) Transmission Lines
    - Several Hundred Miles
    - Switching Stations
        - Transformers
        - Circuit Breakers

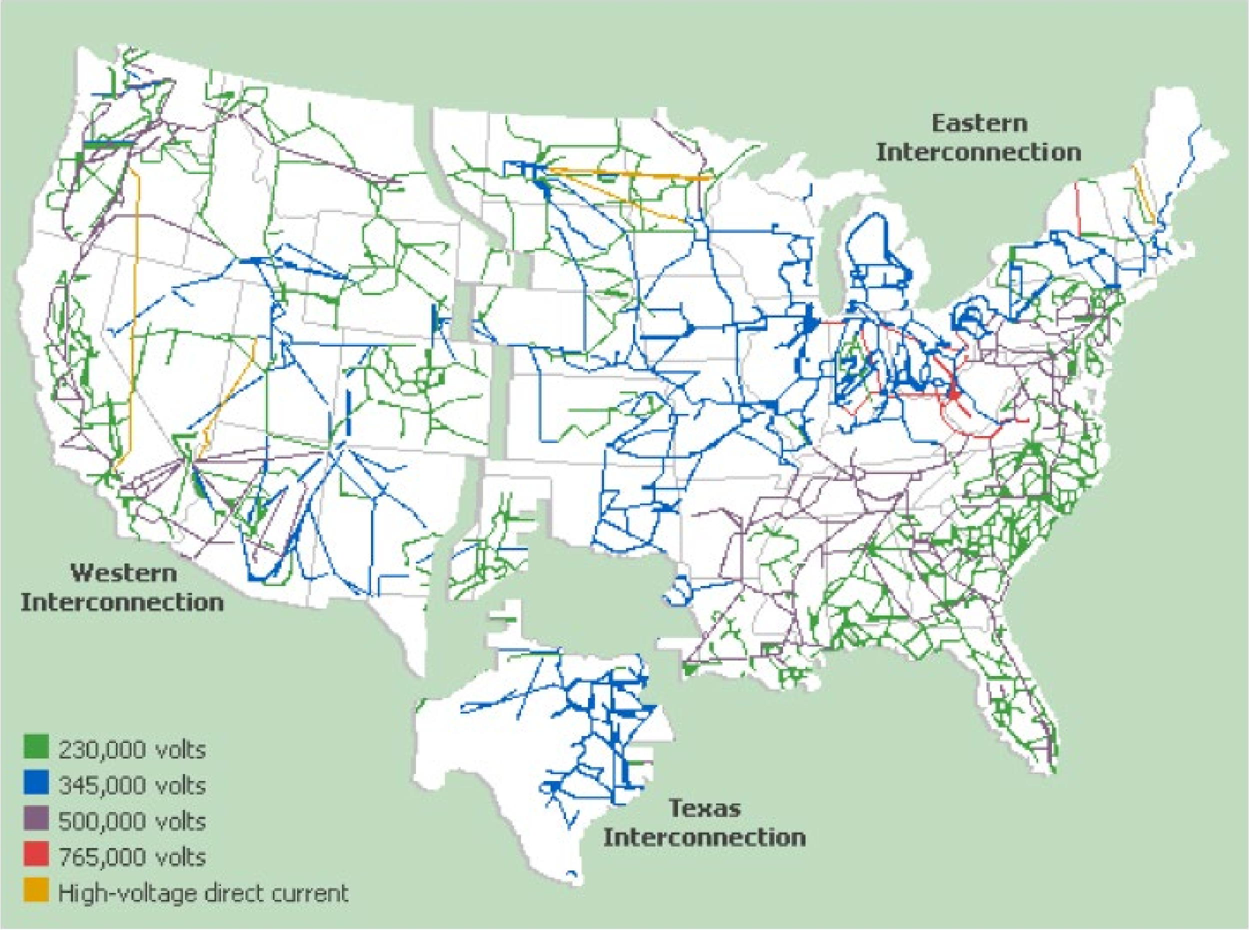
# Power Systems

- The Power Transmission Grid in the United States:



# Power Systems

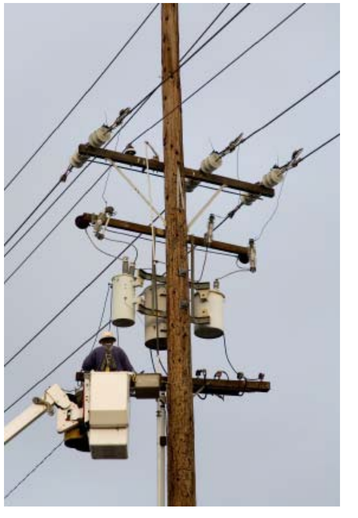
- Major Inter-connections in the United States:




www.geni.org

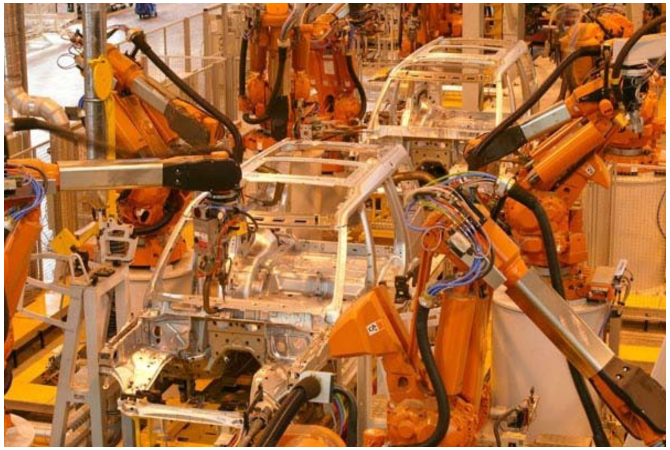
# Power Systems

- Power Distribution:
    - Medium Voltage (MV) Transmission Lines (< 69 kV)
    - Power Deliver to Load Locations
    - Interface with Consumers / Metering
    - Distribution Sub-stations
        - Step-Down Transformers
        - Distribution Transformers



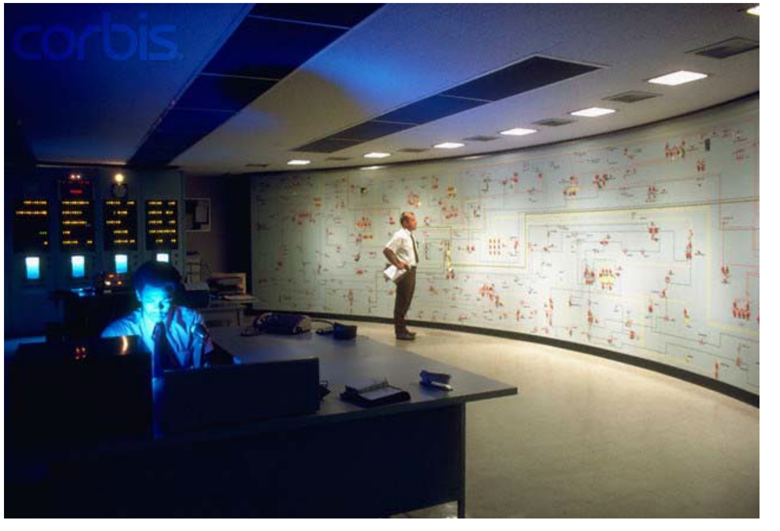
# Power Systems

- Power Consumption:
    - Industrial
    - Commercial
    - Residential
    - Demand Response
        - Controllable Load
        - Non-Controllable



# Power Systems

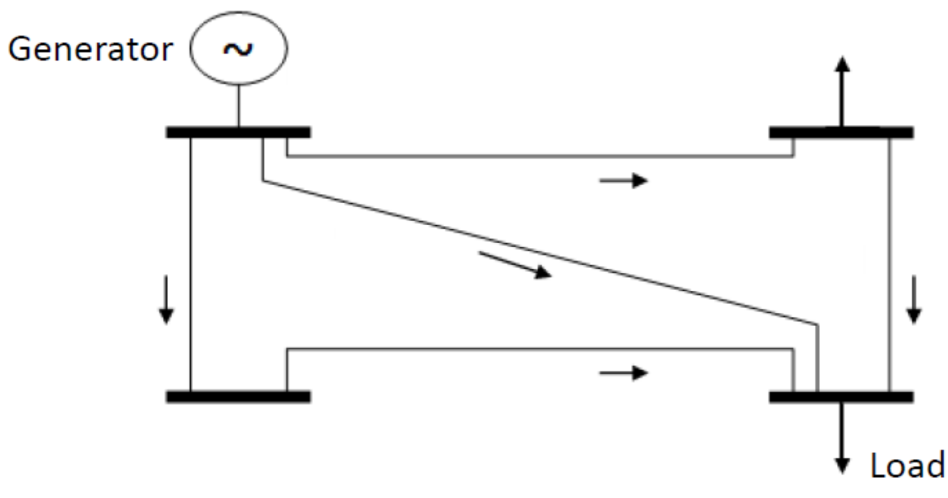
- Power System Control:
    - Data Collection: Sensors, PMUs, etc.
    - Decision Making: Controllers
    - Actuators: Circuit Breakers, etc.



# Power Grid Graph Representation

**Nodes**: Buses

**Links**: Transmission Lines



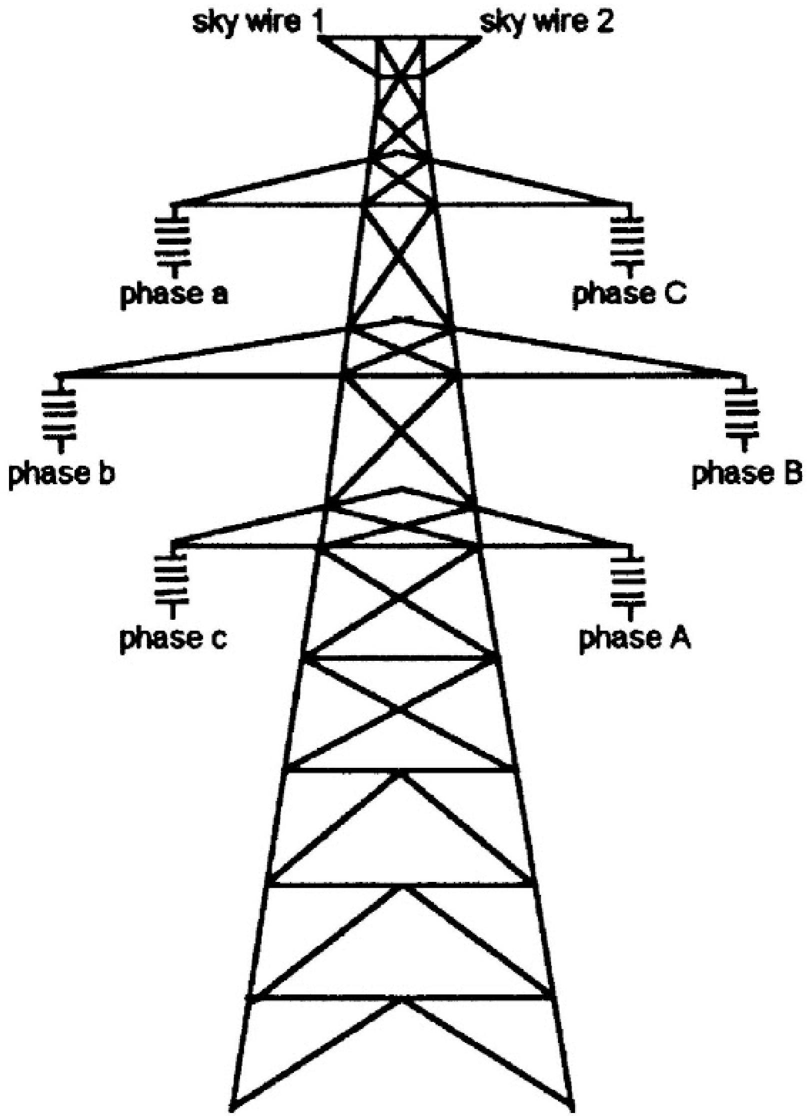
# Blanced Three-Phase Systems

- A balanced three-phase ($\phi$) system has
  - three voltage sources with equal magnitude, but with an angle shift of 120°
  - equal loads on each phase
  - equal impedance on the lines connecting the generators to the loads
- Bulk power systems are almost exclusively 3$\phi$
- Single-phase is used primarily only in low voltage, low power settings, such as residential and some commercial

# Advantages of Three-Phase Power

- Can transmit more power for same amount of wire (twice as much as single phase)
- Torque produced by three-phase machines is constant
- Three-phase machines use less material for same power rating
- Three-phase machines start more easily than single-phase machines

# Three-Phase Transmission Lines



# Three-Phase Transmission Lines

# What is Smart Grid?

**Q: What is Smart Grid?**

**Short Answer: Smart Grid = IT + Electrical Grid**

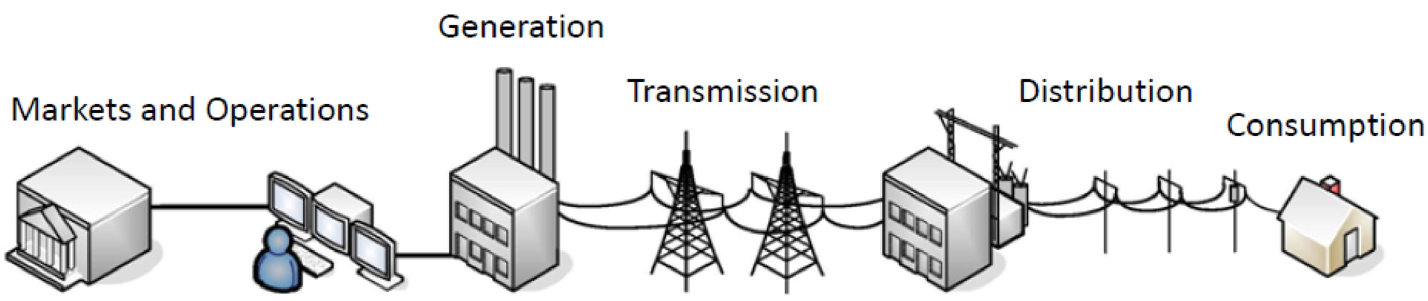
# What is Smart Grid?

- According to the U.S. Department of Energy (DoE)

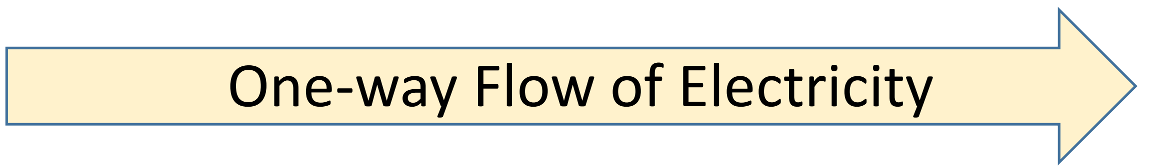
Smart grid" generally refers to a class of technologies that people are using to bring utility electricity delivery systems into the 21st century, using computer-based remote control and automation. These systems are made possible by two-way digital communications technologies and computer processing that has been used for decades in other industries. They are beginning to be used on electricity networks, from the power plants and wind farms all the way to the consumers of electricity in homes and businesses. They offer many benefits to utilities and consumers – mostly seen in big improvements in energy efficiency and reliability on the electricity grid and in energy users' homes and offices.

# What is Smart Grid?

- Traditional Power Grid:



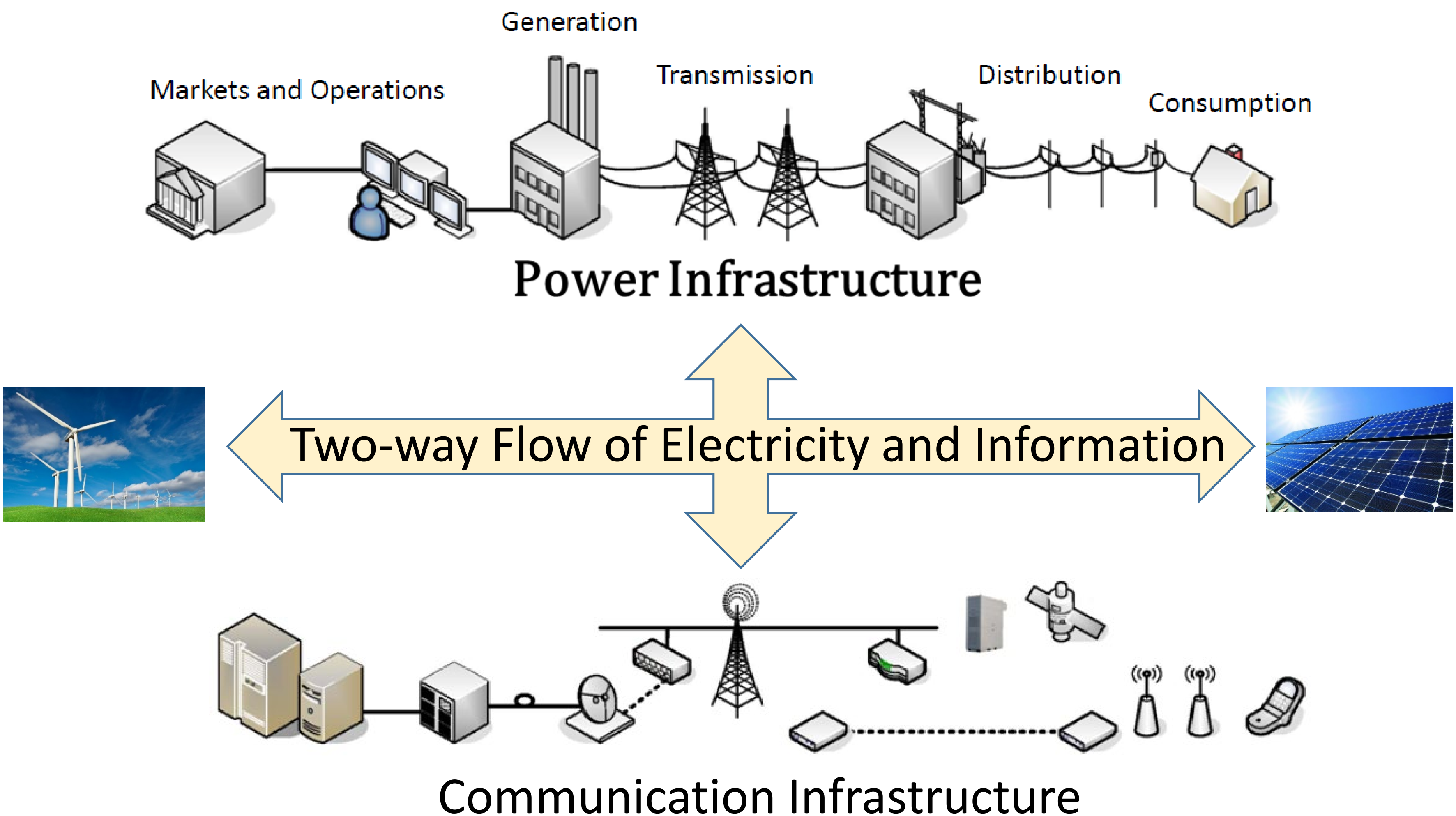

**Power Infrastructure**




Centralized, bulk generation
Heavy reliance on coal and oil
Limited automation
Limited situational awareness
Consumers lack data to manage energy usage

# What is Smart Grid?

- Traditional Power Grid:



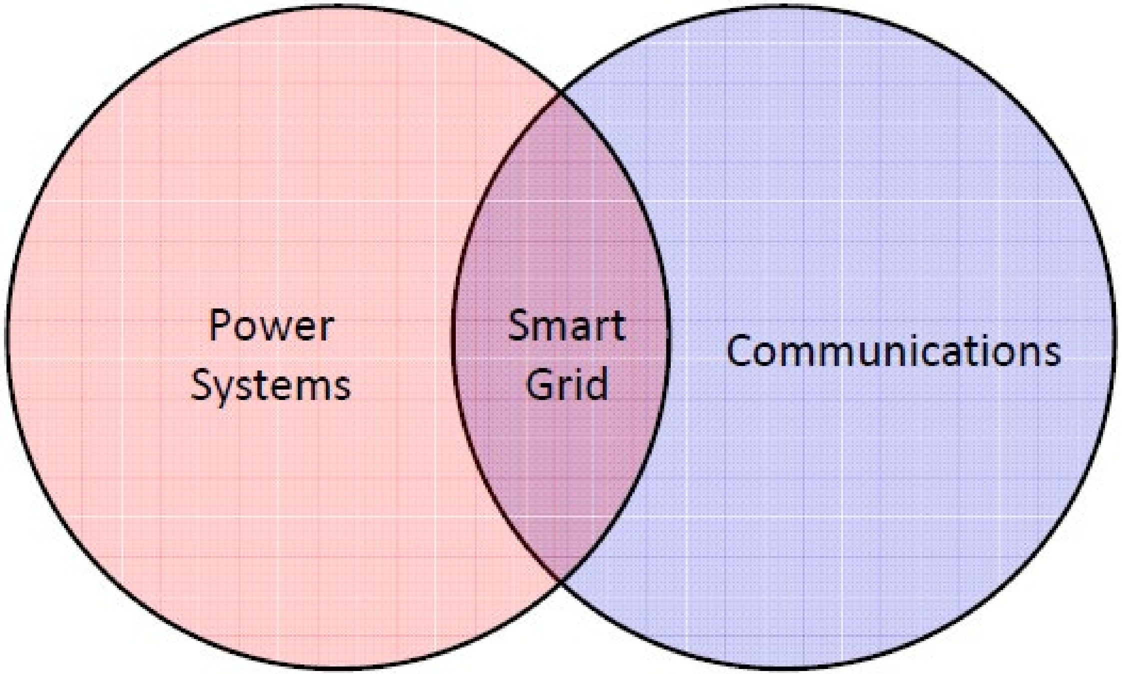
# What is Smart Grid?

- Brief Comparison between Existing Grid and Smart Grid:

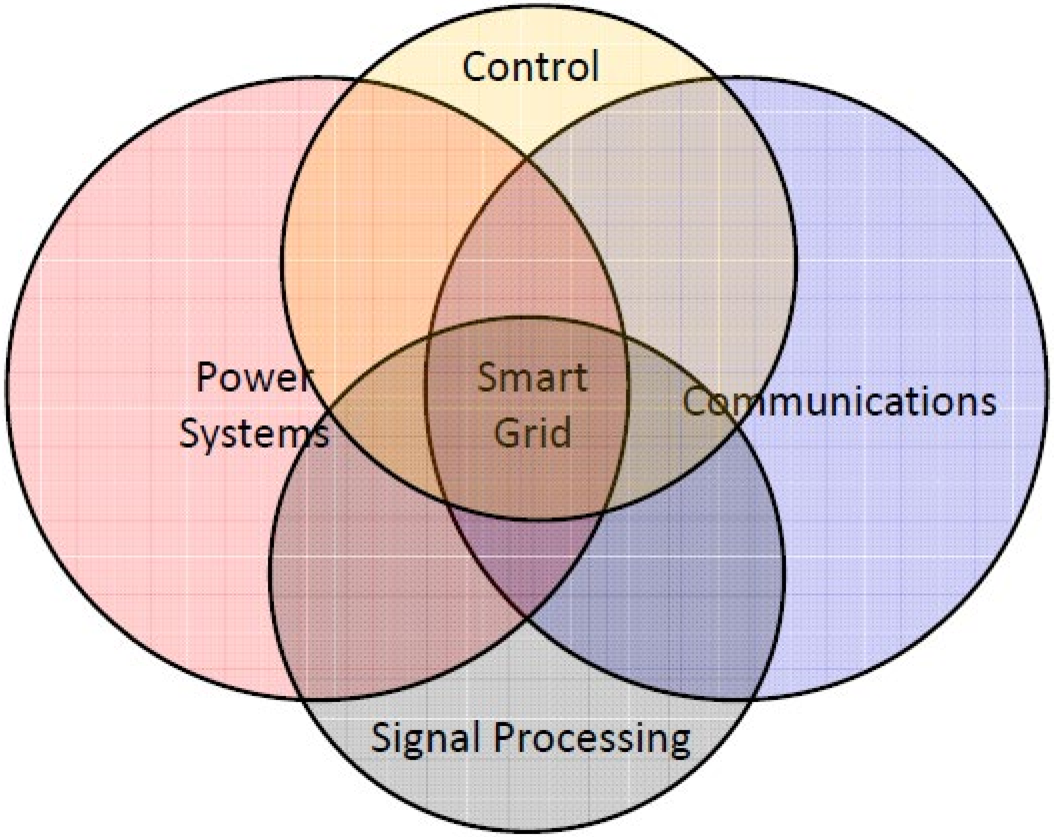
| Existing Grid | Smart Grid |
|---|---|
| Electromechanical | Digital |
| One-way communication | Two-way communication |
| Centralized generation | Distributed generation |
| Few sensors | Sensors throughout |
| Manual monitoring | Self-monitoring |
| Manual restoration | Self-healing |
| Failures and blackouts | Adaptive and islanding |
| Limited control | Pervasive control |
| Few customer choices | Many customer choices |

Ref: Farhangi 2010.

# A Multi-disciplinary Field



# A Multi-disciplinary Field



# Anticipated Smart Grid Benefits

- According to National Inst. of Standards and Technology (NIST):

  1. Improving Power Reliability and Quality
     - Better monitoring using sensor networks and communications
     - Better and faster balancing of supply and demand

  2. Minimizing the Need to Construct Back-up (Peak Load) Power Plants
     - Better demand side management
     - The use of advanced metering infrastructures

# Anticipated Smart Grid Benefits

3. Enhancing the capacity and efficiency of existing electric grid
   - Better monitoring using sensor networks and communications
   - Consequently, better control and resource management in real-time

4. Improving Resilience to Disruption and Being Self-Healing
   - Better monitoring using sensor networks and communications
   - Distributed grid management and control

# Anticipated Smart Grid Benefits

5. Expanding Deployment of Renewable and Distributed Energy Sources

   - Better monitoring using sensor networks and communications
   - Consequently, better control and resource management in real-time
   - Better demand side Management
   - Better renewable energy forecasting models
   - Providing the infrastructure / incentives

# Anticipated Smart Grid Benefits

6. Automating maintenance and operation
    - Better monitoring using sensor networks and communications
    - Distributed grid management and control

7. Reducing greenhouse gas emissions
    - Supporting / encouraging the use of electric vehicles
    - Renewable power generation with low carbon footprint

# Anticipated Smart Grid Benefits

8. Reducing oil consumption
   - Supporting / encouraging the use of electric vehicles
   - Renewable power generation with low carbon footprint
   - Better demand side Management

9. Enabling transition to plug-in electric vehicles
   - Can also provide new storage opportunities

# Anticipated Smart Grid Benefits

10. Increasing consumer choice

    - The use of advanced metering infrastructures
    - Home automation
    - Energy smart appliances
    - Better demand side Management

# Anticipated Smart Grid Benefits

- Average Cost for 1 Hour of Power Interrupt:

| INDUSTRY | AMOUNT |
|---|---|
| Cellular communications | $41,000 |
| Telephone ticket sales | $72,000 |
| Airline reservation system | $90,000 |
| Semiconductor manufacturer | $2,000,000 |
| Credit card operation | $2,580,000 |
| Brokerage operation | $6,480,000 |

Ref: U.S. Department of Energy

- Smart grid is worth investing?

# Smart Grid Priority Areas

| Eight Priority Areas to Build a Smart Grid (Identified by NIST) |
|---|
| 1. Demand Response and Consumer Energy Efficiency |
| 2. Wide-Area Situational Awareness |
| 3. Energy Storage |
| 4. Electric Transportation |
| 5. Advanced Metering Infrastructure |
| 6. Distribution Grid Management |
| 7. Cyber Security |
| 8. Network Communications |

# Smart Grid Standards

- IEEE is a key player in Smart Grid Standardization
  - Nine Relay-based Phasor Measurement Units (PMUs)
  - IEEE has over 100 Smart Grid-related approved standards:
    - http://smartgrid.ieee.org/standards/approved-ieee-smart-gridstandards
  - IEEE also has several Smart Grid-related pending standards:
    - http://smartgrid.ieee.org/standards/proposed-standards-related-tosmart-grid

# What is Microgrid?

- A group of generators and loads
- Allows smooth renewable energy integration
- Acts as a single controllable electrical system
- Can operate
    - Grid-connected
    - islanded (during blackouts)

# What is Microgrid?

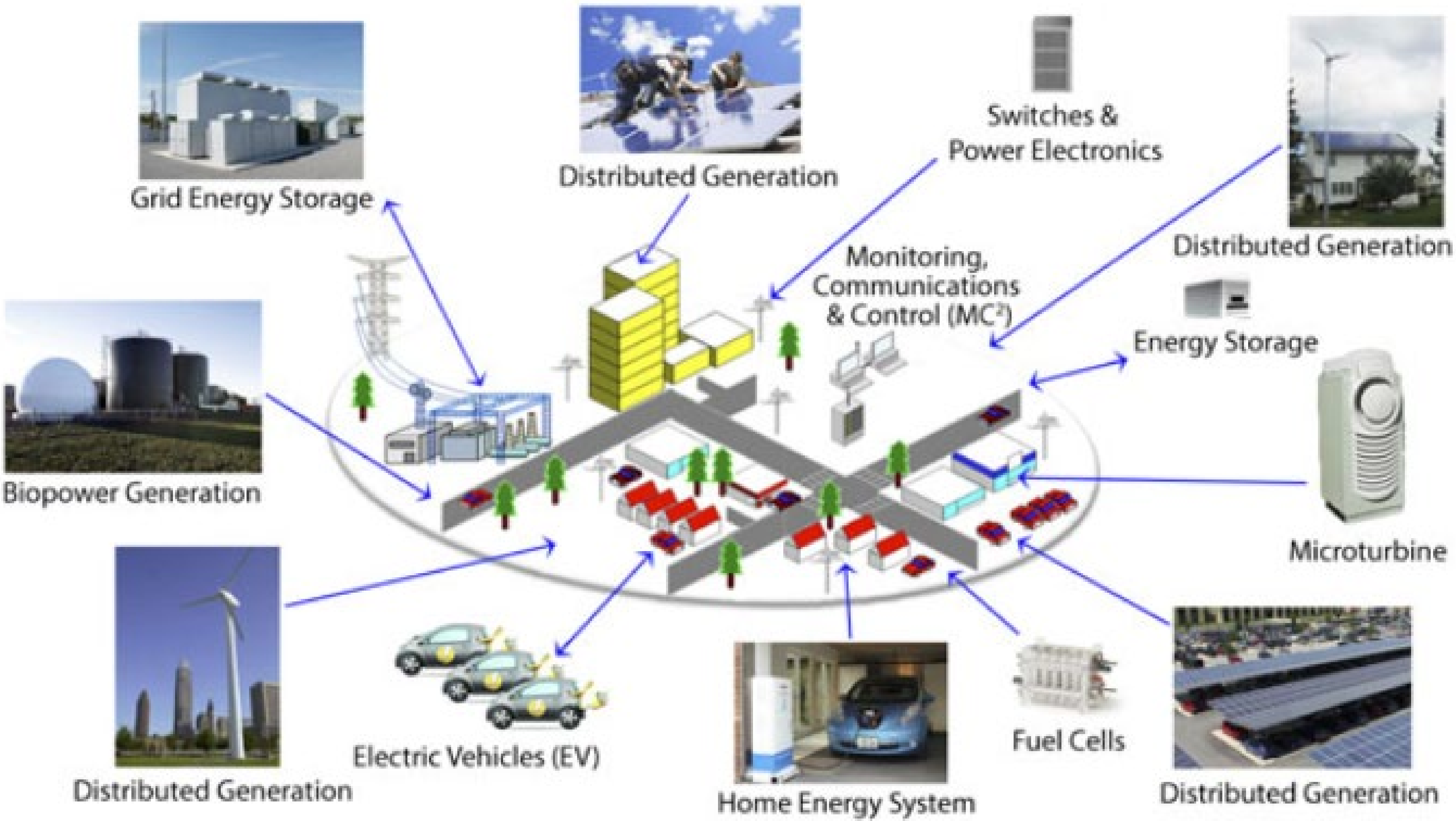
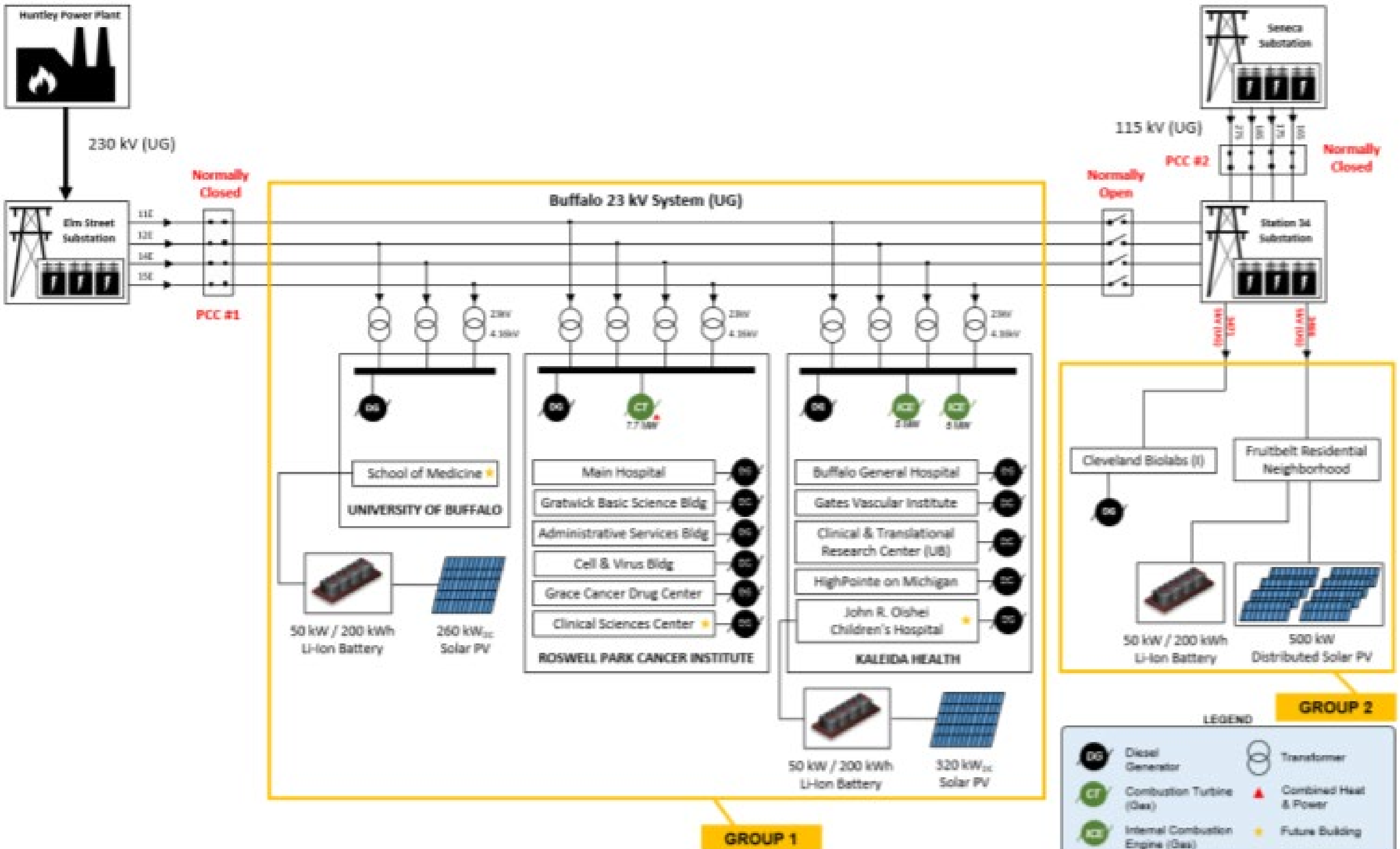


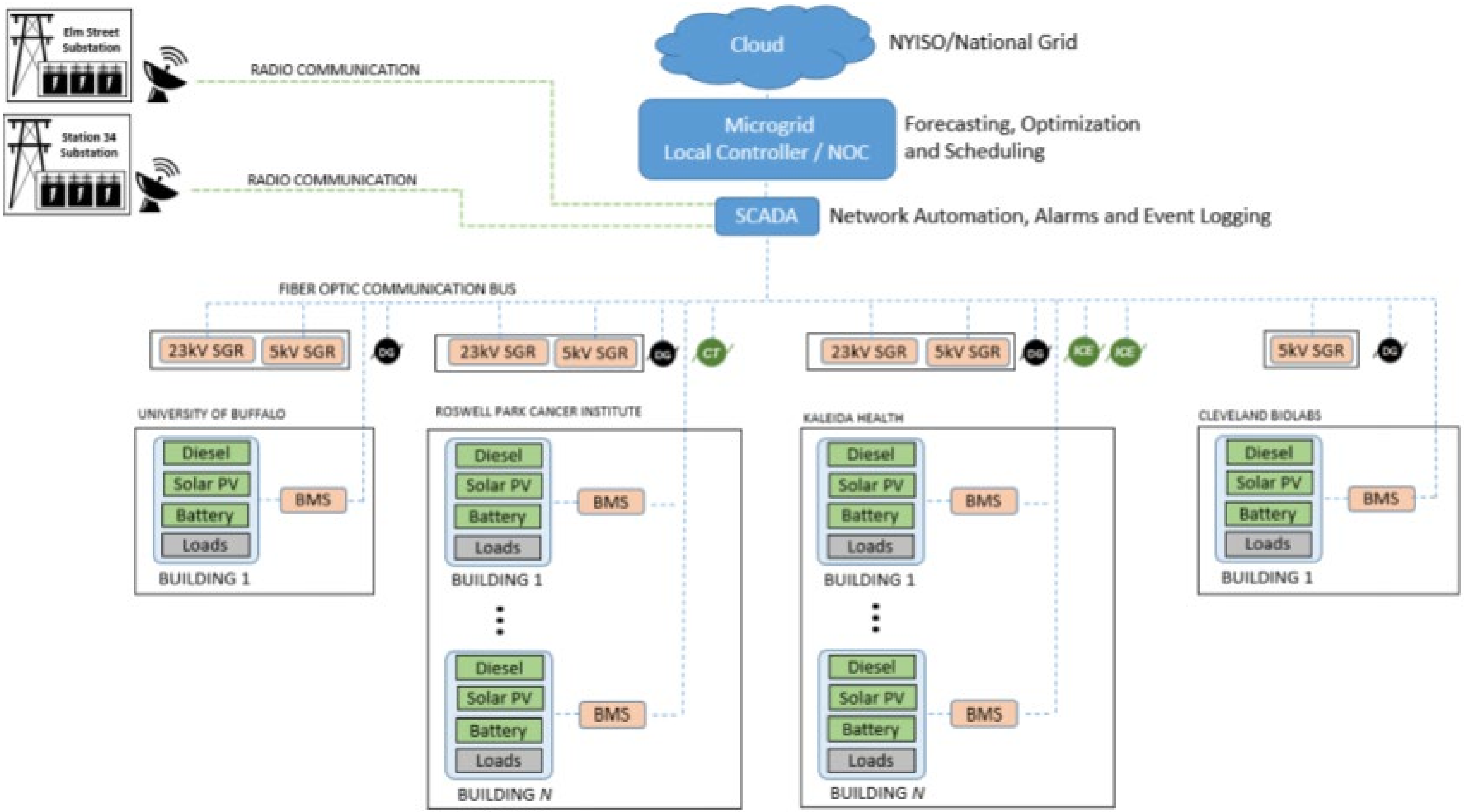

Image Courtesy of Clean Coalition

# Campus Microgrid

- One-line diagram for proposed Buffalo Niagara Medical Campus (BNMC) Community Microgrid

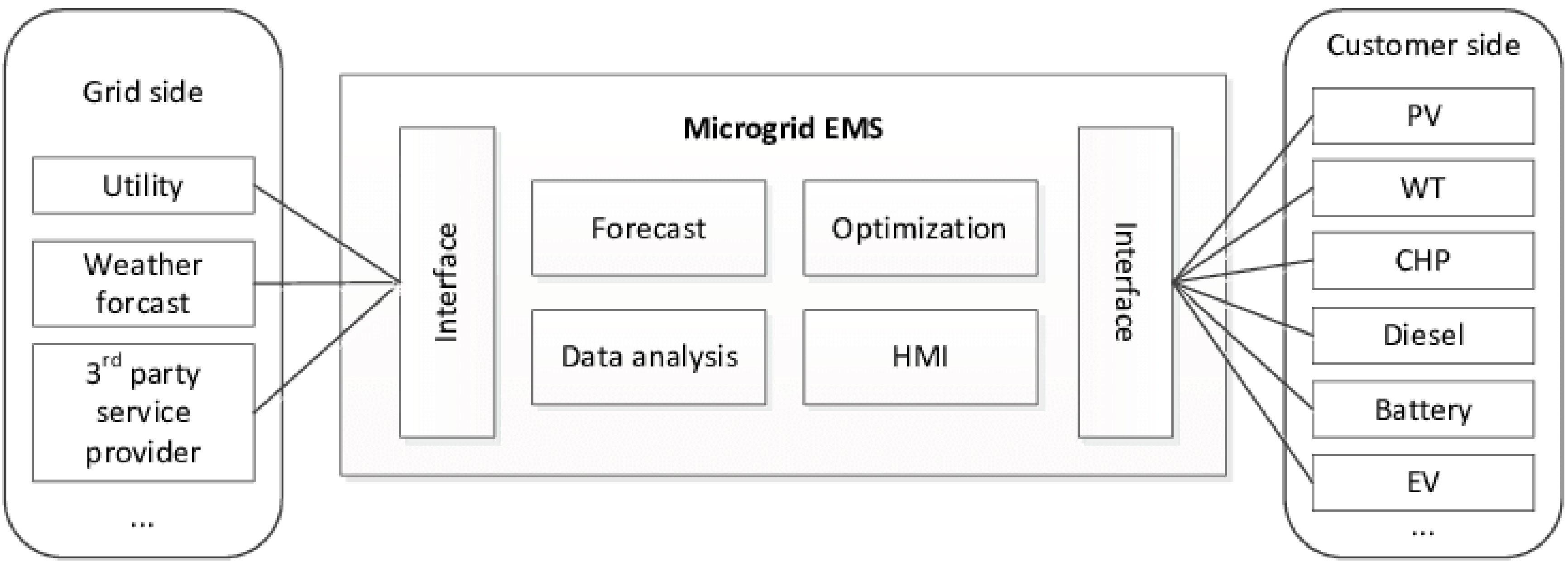


# High Level IT/ Telecom Infrastructure – BMNC Community

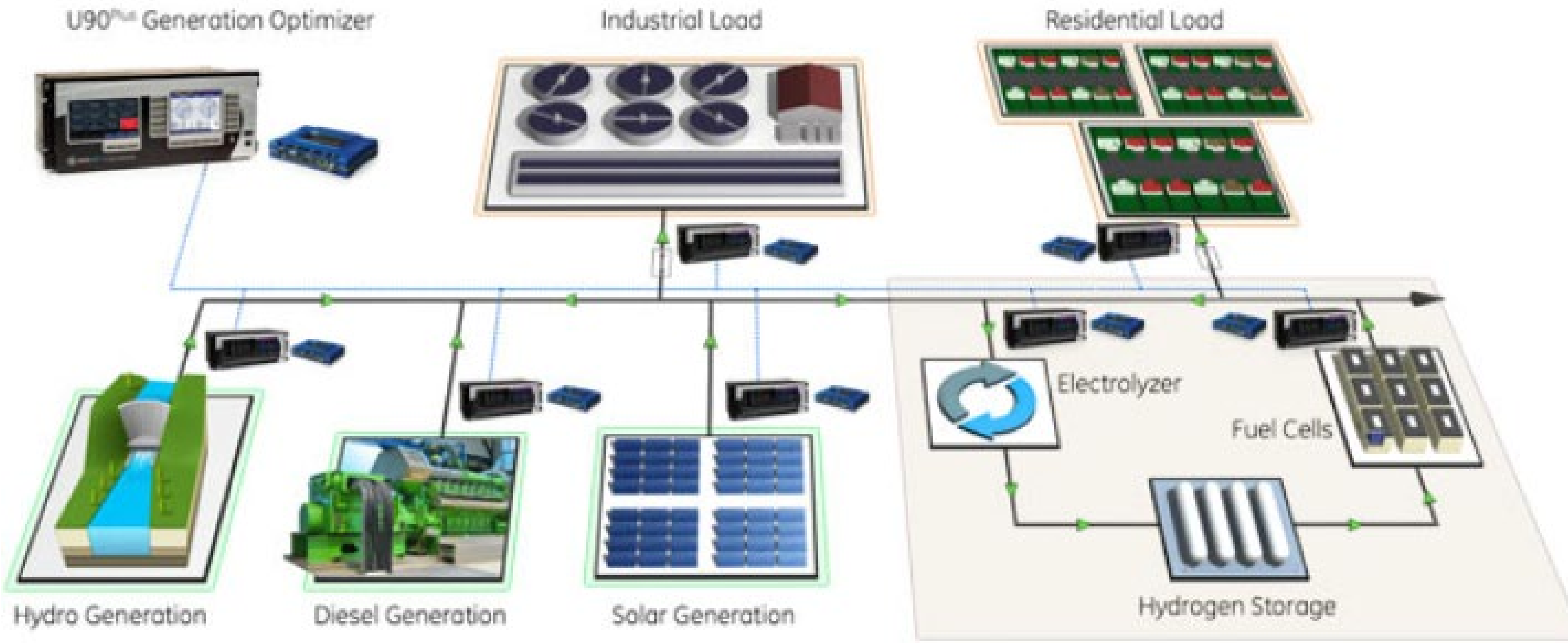


# Microgrid Control System - MEMS

- Microgrid Energy Management System (MEMS)

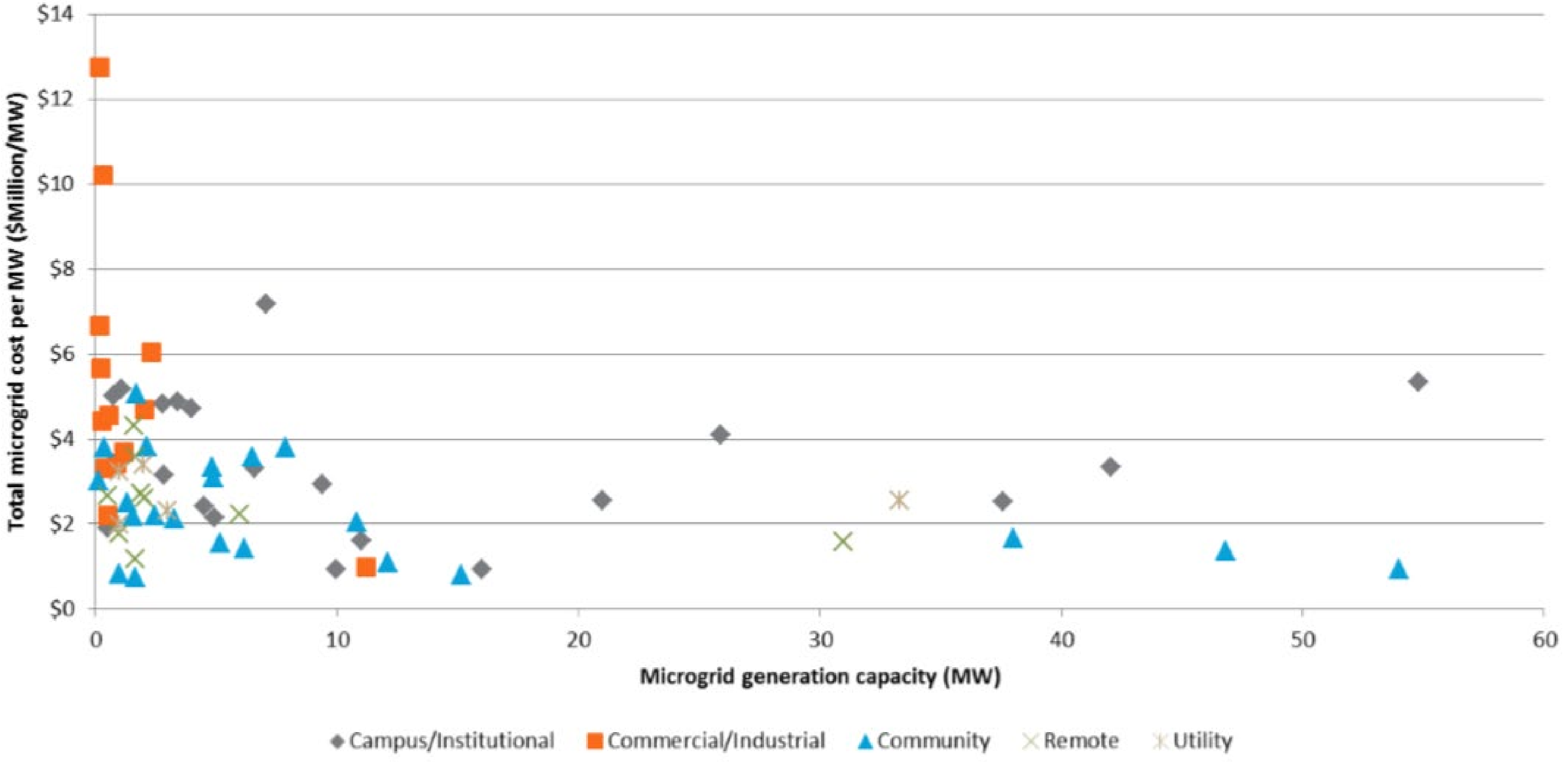


# Sample Microgird Control System (GE U90)



# Microgrid Costs in $/MW

- Normalized microgrid costs by size of the project in megawatts and by market segment



# MGCS Control Applications

- Optimization
- Campus resource management and reporting
- Electricity cost and saving calculations
- Ancillary services
- Reserve capacity management

# MGCS Transition Management

- Planned/ Intentional Islanding
- Unplanned/ Unintentional Islanding
- Black Start
- Service restoration
- Seamless transition
- Re-synchronization
- BESS Shutdown/ Offline/ Idle

# Microgrid Challenges

- Legal and regulatory uncertainty
- Interconnection policy
- Utility regulation
- Utility opposition

# References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