Smart Grid and NFPA Electrical Safety Codes and Standards

IAEI Western Section Presentation

Lonny Simonian, PE
Associate Professor
Principal Investigator

Dr. Thomas Korman, PE
Associate Professor
Co Investigator

Dr. Frederick W. Mowrer
Professor-in-Residence / Director Fire Protection Engr.

David Phillips
Graduate Student
Fire Protection Engr.

THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

Smart Grid Project Background

- NFPA invited to participate in NIST Smart Grid Rapid Standardization Initiative
- Concern that safety of the built infrastructure not appropriately addressed
- Proactive initiative to ensure that the NEC and other NFPA electrical safety standards keep pace with Smart Grid developments

Smart Grid Project Background

- NFPA Smart Grid Task Force formed - 2009
- Grant request submitted to NIST to provide focused support to task force activity - accelerate and support interoperable codes and standards development for Smart Grid
- Approved summer 2010

THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

Smart Grid Project Background

- Smart Grid technology provides a means to manage the utility generation resources of the grid as well as manage loads on the grid (facility loads)
- The primary conventional generation resources include:
  - o Fossil fuel plants
  - o Nuclear plants
  - o Hydro electric facilities

Smart Grid Project Background

- Utility owned resources may also include
  - Gas turbines (for peak demand loads)
  - Wind farms
  - Photovoltaic plants
  - Micro Combined Heat and Power (MicroCHP)
  - Electric vehicles
  - Community Energy Storage Systems

Smart Grid Project Background

- The grid also includes a number of nonutility grid connected generation resources, which include:
  - Photovoltaic
  - Small scale wind turbine
  - Micro hydro
  - Fuel cells
  - Micro Combined Heat and Power (MicroCHP)
  - Electric vehicles
  - Community Energy Storage Systems

Smart Grid Project Background

- The smart grid facilitates the bi-directional flow of power to make the greatest use of these distributed resources by allowing them to be dispatched where and when they are needed
- It's also based on the concept of being able to better manage load, including selective load shedding, when needed
- It includes a communications infrastructure to manage the sources and the loads
- This new technology has implications for:
  - Electrical safety
  - Personnel safety
  - Fire Safety
- The smart grid includes equipment on the customer side of the service point
- The smart grid may permit control from the utility side of the service point

Smart Grid Project Background

The National Electrical Code® has formed a Smart Grid Task Group that is in the preliminary stages of addressing the impact of the Smart Grid and related emerging building electrical systems that will interface with the grid but are on the customer side of the service point

Smart Grid Research Objectives

1. **Technology Review and Safety Assessment** of the emerging technologies associated with Smart Grid implementation and their impacts on the safety features of the built environment
2. **Regulatory Development and Needs Assessment** of the current weaknesses/gaps in the U.S. fire and electrical safety codes and standards which will impede widespread implementation of this technology
3. **Roadmaps** of needed specific codes and standards development/changes and areas where additional data/research on safety aspects is required

Project Steering Committee Members

Al Scolnik, National Electrical Manufacturers Association

John Thompson, Underwriters Laboratories, Inc.

Dave Clements, International Association of Electrical Inspectors

Bill Galloway, SC State Fire Marshal's office, representing International Fire Marshals Association

Mike Johnston, NECA, Chair, NEC Correlating Committee

Jim Pauley, Schneider Electric Company

Dean Prochaska, Smart Grid Conformance Program Office, NIST

Mark Earley, Chief Electrical Engineer, National Fire Protection Association

Shawn Paulsen, CSA-International

THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

Industry Workshop March 14 & 15 Washington DC

- Review and input from leaders within the NFPA safety standards development community on the project
- Input for NEC Smart Grid Task Force in consideration of upcoming NEC code change cycle

Outcome

- Report – available for free download at nfpa.org/foundation
- Inspector's Guide
- IAEI regional meeting presentations
- Webinars (date is TBD)
- Technical basis for submitted NEC changes

Smart Grid Customer Domain

nist.gov

Smart Grid Technologies Overview

- Building Metering/Information Systems Energy Management Systems
- Energy Microgeneration, Co-Generation, and Generation
- Energy Storage Systems

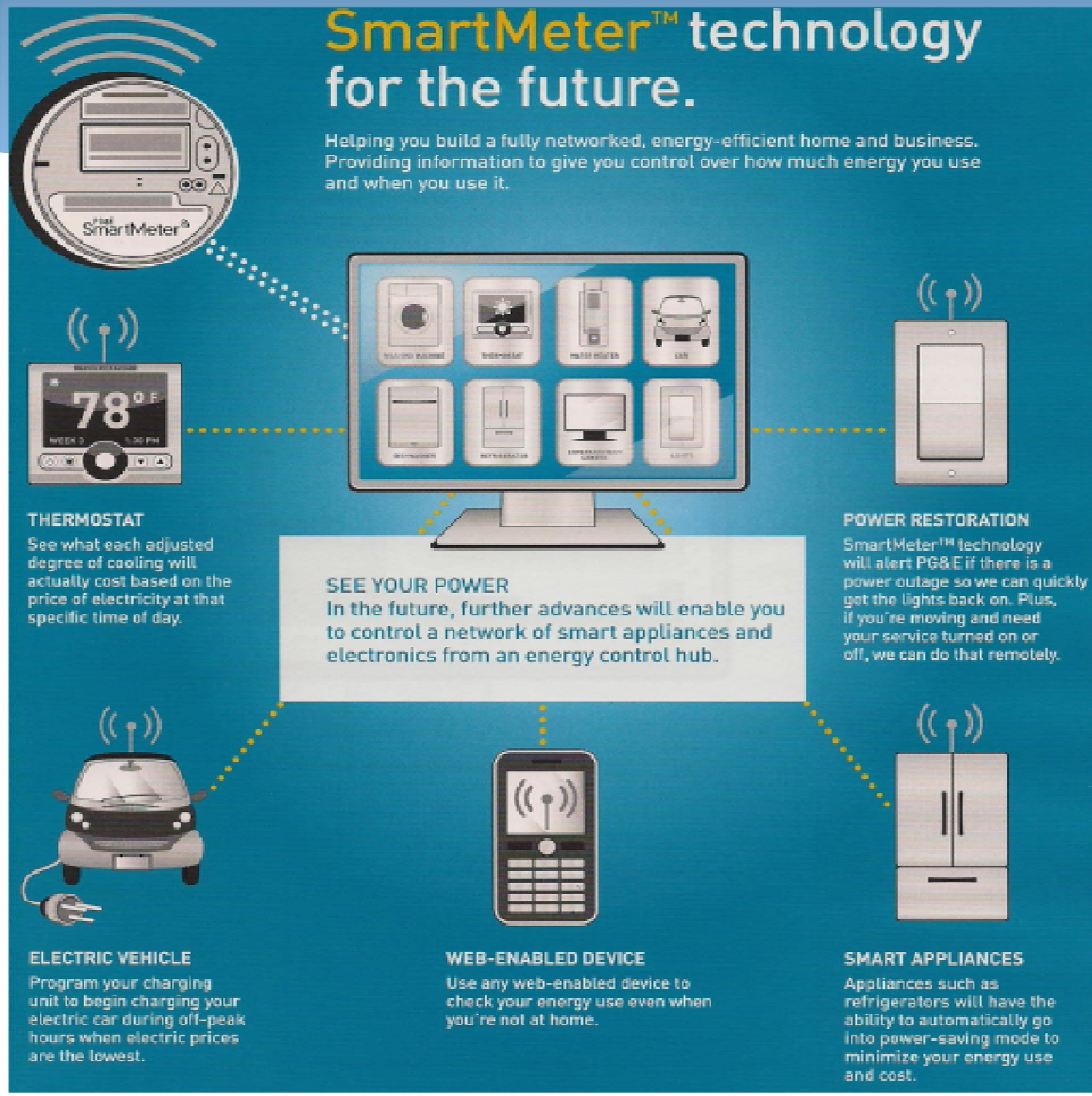
Building Metering/Information Systems

- Smart Meters
- Energy Management Systems
- Time of Use Metering/Rate Structures
- Load Shedding/Demand Response

Smart Meters

- An advanced electric meter that records consumption in intervals of one hour or less and communicates that information at least daily via some communications network back to the utility for monitoring and billing purposes
- Enable two-way communication between the customer's meter and the electrical utility serving the customer
- Use real-time or near real-time sensors, power outage notification, and power quality monitoring

Smart Meters[1]



THE FIRE PROTECTION RESEARCH FOUNDATION

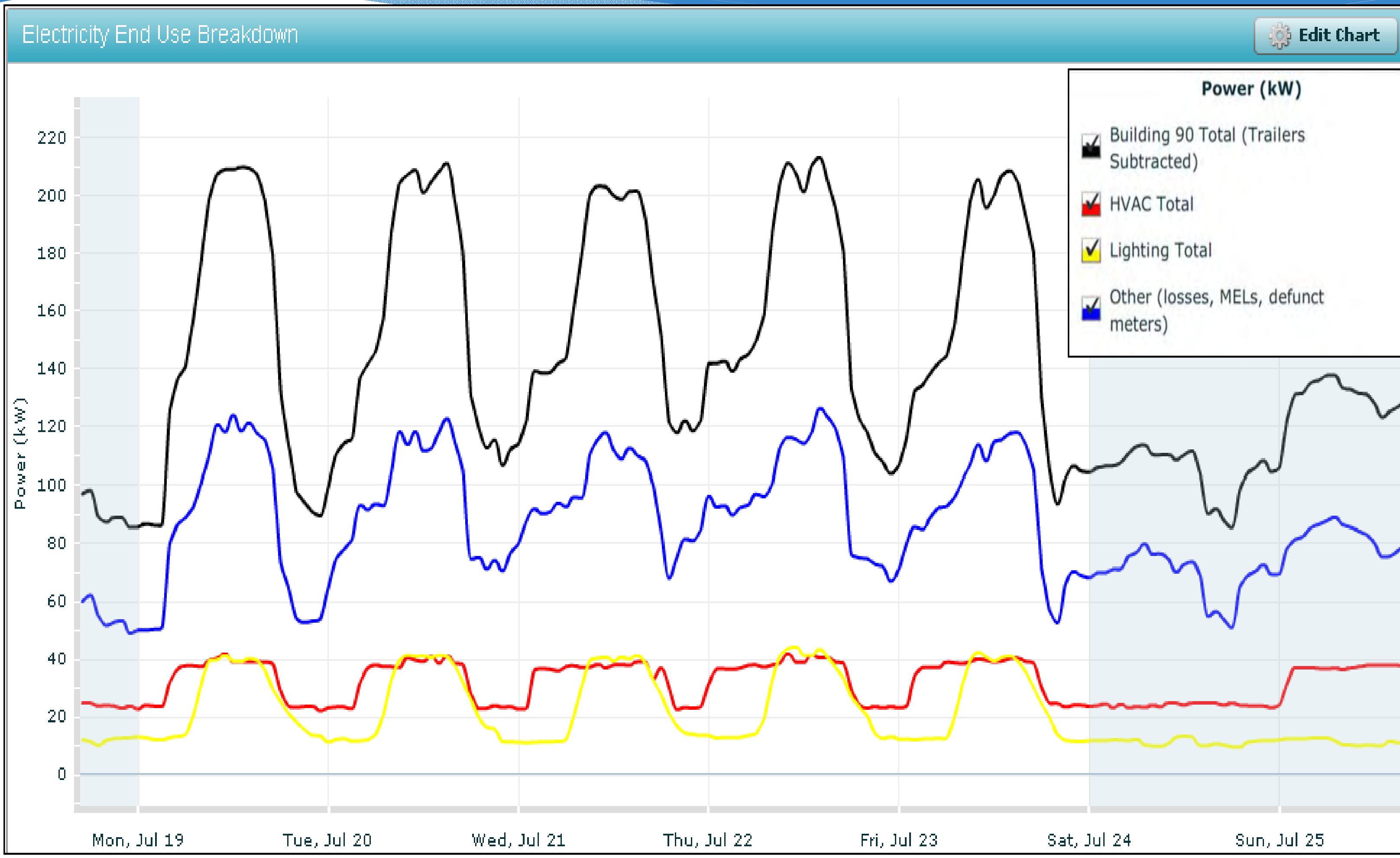
pg&e.com

CAL POLY FIRE PROTECTION ENGINEERING

Energy Management Systems

- Although common in commercial facilities, Energy Management System (EMS) - also know as Energy Information Systems (EIS) and Energy Monitoring and Control Systems (EMCS) - are relatively new to residential
- A Home Area Network (HAN) interfaces the user with smart grid technology such as smart meters, smart plugs, and smart appliances
- A HAN may be hard-wired; however, most new systems use wireless technologies, enabling retrofitting into existing homes
- If a cabled system is used, cabling needs to be deployed from the electric meter to each major appliance
- Power-line carrier may be used as the communications channel.
- Smart plugs or switches can be used to connect the major appliances to the HAN

EIS Dashboard – Institutional Building



THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

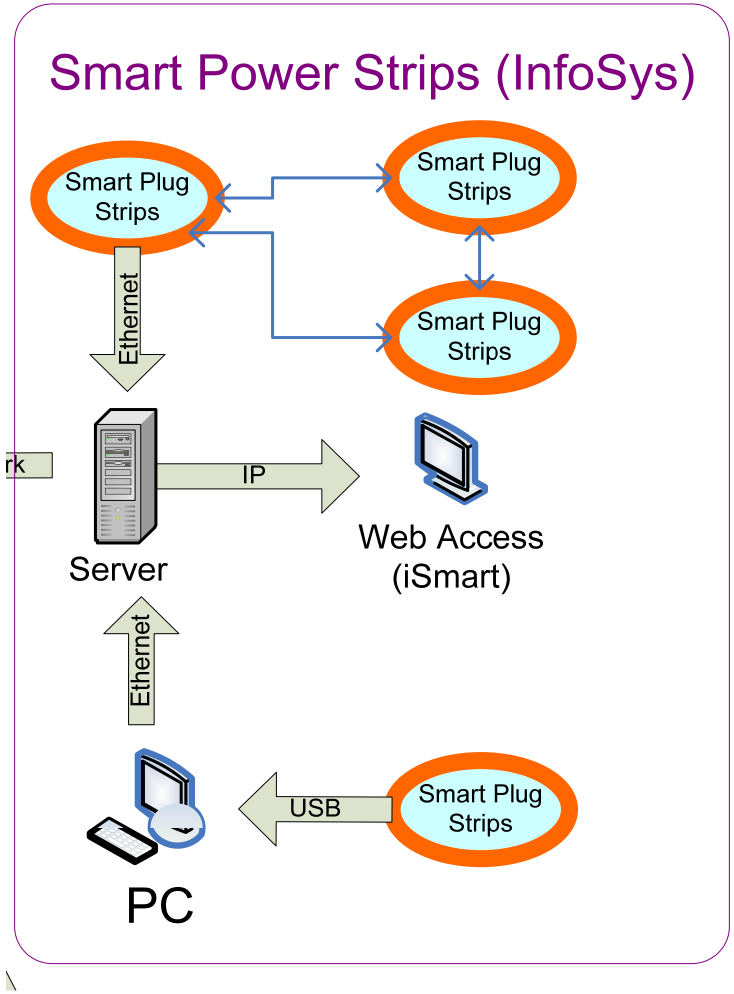
Time of Use (TOU) Metering

- TOU net metering employs a specialized reversible smart meter that is programmed to determine net electricity consumption (or contribution) any time during the day
- Time-of-use allows utility rates and charges to be assessed based on when the electricity was used (i.e., day/night and seasonally)

Load Shedding/Demand Response

- Load shedding is an intentional, utility-initiated loss of electrical power to a specific customer or group of customers
- Utility companies have historically used load shedding as a last-resort in order to avoid a total blackout of the power system
- With smart meters, load shedding also may be implemented to selectively "shed" designated loads during high demand
- Demand response appliances could reduce an electrical utility's base load during peak usage hours via a request from either the customer or utility
- Residential smart appliances (such as air-conditioning, ovens, dryers, etc.) are being developed to communicate, be monitored, and controlled by a smart meter

Smart Plug Strip Configuration



Energy Microgeneration, Co-Generation, and Generation

- Photovoltaic
- Small scale wind turbine
- Micro hydro
- Ground source heat pump
- Fuel cell
- Plant microbial fuel cell
- Micro Combined Heat and Power (MicroCHP)

Photovoltaic (PV)

- Employs solar panels comprising a number of cells
- Often associated with buildings – integrated, mounted, or nearby
- Arrays are incorporated into the roof or walls of a building
- Roof tiles with integrated PV cells are also becoming more common

Small Scale Wind Turbine

- Conversion of wind energy into electricity
- Capable of producing up to 100 kW of electrical power
- May be utility interactive or may use batteries for energy storage

Micro Hydro

- Capable of producing up to 100 kW of power
- Can provide power to an isolated home or small community
- Complements PV systems - often water flow is highest in the winter when solar energy is at a minimum

Fuel Cell

- Electrochemical cell that converts a source fuel into an electric current
- Many combinations of fuels and oxidants are possible
- Hydrogen fuel cell uses hydrogen as its fuel and oxygen (usually from air) as its oxidant
- Other fuels include hydrocarbons and alcohols - other oxidants include chlorine and chlorine dioxide

Plant Microbial Fuel Cell (MFC)

- Device that converts chemical energy to electrical energy by the catalytic reaction of microorganisms
- Microbial fuel cells have a number of potential uses - harvesting the electricity produced for a power source
- Any organic material could be used to ‘feed’ a fuel cell.
- Conceivable that MFCs could be installed in septic tanks, where bacteria would consume waste material from the water and produce supplementary power for a building
- MFCs are a clean and efficient method of energy production

Micro Combined Heat and Power (MicroCHP)

- Operates like a combination furnace, hot water heater and electricity provider—all in one compact unit
- Hot air and water form the waste heat
- MicroCHPs are usually less than 5 kWh for a residential / commercial building fuel cell
- Generates electric power 24/7 (selling excess power back to the grid when it is not consumed)
- Connected to the grid through the panel using net metering - able to fit inside a mechanical room or outside a home or business
- Designed to integrate with existing electrical and hydronic systems
- System automatically switches to a grid-independent operational mode to provide continuous backup power for dedicated circuits in a residence while the grid is down

Energy Storage Systems

- Batteries
- Uninterruptible Power Supply (UPS) systems
- Thermal Energy Storage
- Vehicle-to-Grid Storage
- Community Energy Storage (CES)

Batteries

- An early solution to the problem of storing energy for electrical purposes was the development of the battery as an electrochemical storage device
- Batteries have previously been of limited use in electric power systems due to their relatively small capacity and high cost
- Newer battery technologies have been developed that can now provide significant utility scale load-leveling capabilities
- In addition to batteries, capacitive storage provides another possible solution to deal with the intermittent issue of solar and wind energy

Uninterruptible Power Supply (UPS) Systems

- Although not a conventional energy storage device, UPS contain storage batteries which provide power to select loads
- The on-battery run time of most UPS is relatively short—5 to 15 minutes being typical for smaller units—but sufficient to allow time to bring an auxiliary power source on line, or to properly shut down the connected equipment
- Although once previously reserved for large installations of 10 kW or more, advances in technology have now permitted UPSs to be available as a common consumer device, supplying 500 watts or less
- In a smart grid environment, a UPS's storage batteries could lower demand or supply the grid during peak hours or in response to an electricity provider's request

Thermal Energy Storage (TES)

- The most popular form of TES for cooling is ice storage, since it can store more energy in less space than water storage and is also less costly than energy recovered via fuel cells or flywheels
- Thermal storage has cost-effectively shifted gigawatts of power away from daytime peak usage periods
- TES works by creating ice at night when electricity is usually less costly, and then using the ice to cool the air in buildings during the hotter daytime periods
- There are several advantages of thermal storage:
  - commercial electrical rates are lower at night
  - it takes less energy to make ice when the ambient temperature is cool at night
  - a smaller (more efficient system) can do the job of a much larger unit by running for more hours

Thermal Energy Storage

- Another form of thermal energy storage is Electric Thermal Storage (ETS)
- In a simple residential ETS system heating units are placed in the rooms where the most heat is required
- During off-peak hours electric energy is converted into heat and stored in high-mass units, or bricks, made of dense ceramic material
- During peak hours an electric fan circulates the heat from the bricks to heat the home
- The temperature is controlled by outside sensors that adjust the amount of power intake to that needed to keep the room(s) at the required comfort temperature

Vehicle-to-Grid Storage

- Almost one million Plug-In Hybrid Electric Vehicle (PHEV) charge points will be needed in the United States by 2015[1]
- Residential charging stations are forecast to increase by 650,000+ units within five years
- There is a projected growth of over 380% in non-residential charging stations in the next five years
- Vehicle-to-Grid energy storage describes the use of electric vehicles (when plugged into the energy grid) to release the stored electrical energy in their batteries back into the grid when needed

1. http://www.pikeresearch.com

Community Energy Storage (CES)

- An approach where smaller packages of battery energy storage are available to more than one customer with limited back-up time
- For residential application, CES are typically 25 kW with one to two hours of back-up time, and are deployed in neighborhoods, on street corners, or along backyard utility rights-of-way serving a cluster of six to ten customers
- CES units are connected on the low-voltage side of the utility transformer and store 120/240-volt power for individual customers
- For commercial applications, CES interconnect several commercial facilities; 3 phase 277/480 volt systems will have the greatest impact amongst facilities situated in a campus environment
- CES units would allow excess energy to be captured locally with less line losses, and re-dispatched when needed

Summary of Smart Grid Technologies- Smart Meters

Description

A meter that monitors and automatically reports a customer's electricity consumption to the utility. Smart meters may also interface with customer's energy systems and devices to provide the customer with additional information, communications with the utility, and demand response or load shedding. Components consist of:

- Energy Management Systems
- Time of Use Metering/Rate Structures
- Load Shedding/Demand Response

The smart meter will be able to provide:

- Home Area Network (HAN) technologies that will give customers more control over the energy usage of appliances, equipment, lighting, etc.
- HAN technology in the home to better match energy supply with demand
- Smart charging for electric vehicles, taking advantage of off-peak rates
- Integration of customers' on-site energy generation to reduce the need for utility energy and a customers' vulnerability to outages
- Smart charging for electric thermal storage systems

Summary of Smart Grid Technologies-
Smart Meters

Possible NEC Issues

- Dramatic increase in data communication between smart grid appliances / plugs and smart meters, or between devices and home energy management / control systems
- Critical circuits for life-safety systems - including special needs equipment such as patient care equipment (ventilators, diagnosis equipment, etc.) - will need to remain powered during load shedding
- Power or control wiring installed by licensed electrical contractors may be required to tie into panelboards / load centers
- Grounding and bonding for all components will need to be provided
- Sensors will be needed to connect major electrical loads to a smart meter
- Susceptibility of smart systems to frequent inrush currents from switching large appliance loads
- Limitation should be established on the amount of harmonics induced from Class 2 wiring
- Equipment to be certified / listed
- Qualification of installers
- Inspection of installations by qualified persons

Summary of Smart Grid Technologies-
Smart Meters

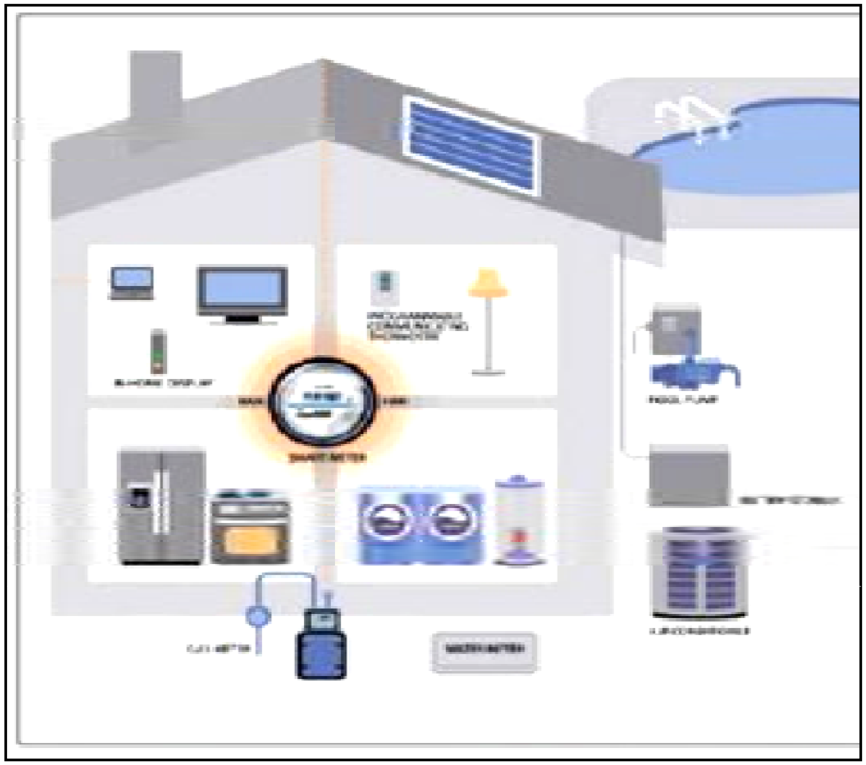
NFPA Articles Affected

- NFPA 70
  - 90
  - 210.11
  - 422.31
  - 424.19
  - 517.31
  - 700.4
  - 701.4
  - 705
  - 705.20
  - 705.40
  - 708.22

- NFPA 70E
  - 100

- NFPA 110
  - 6.2.2
  - 6.2.5

- NFPA 111
  - 6.2.4.2
  - 6.2.4.2.4
  - 6.2.4.5.1
  - 7.1.4
  - 8.4.1



penenergy.com

THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

Summary of Smart Grid Technologies- Energy Micro-generation, Co-Generation, and Generation

Description

Some grid-connected electricity customers have the ability to generate their own electricity through photovoltaic systems, fuel cells, backup generators, etc. These systems may be used to power the customer's equipment or add energy to the grid, especially during peak hours for economic incentives or to help with load shedding. Currently, however, backup generators are not normally permitted to supply power to the grid.

Currently, the most common forms of microgeneration technologies include:

- Photovoltaic
- Small scale wind turbine
- Micro hydro
- Fuel cell
- Plant microbial fuel cell
- Micro Combined Heat and Power (MicroCHP)

Summary of Smart Grid Technologies- Energy Micro-generation, Co-Generation, and Generation

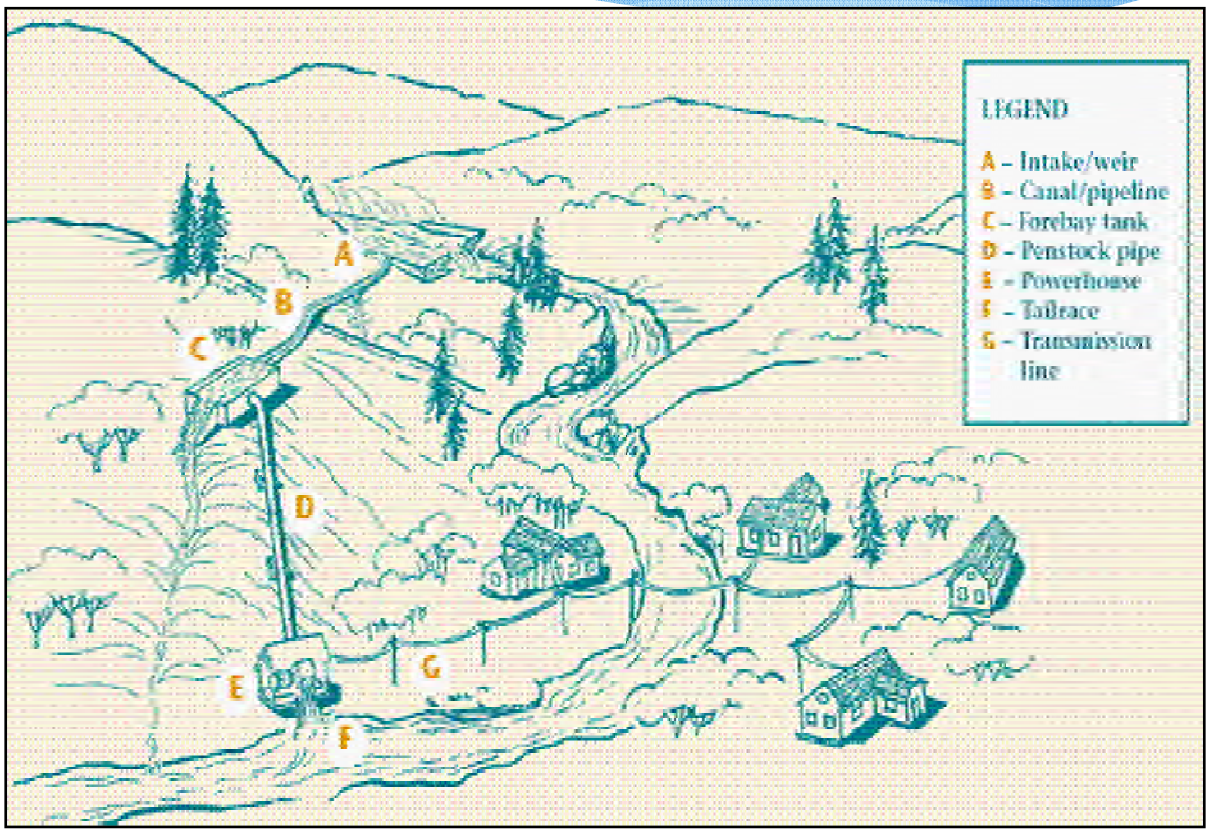
Possible NEC Issues

- Requirements for system interconnection
- Additional notification and safety devices required to alert personnel to and protect them from the presence of two way power
- Protection for chemical conversion of hydrocarbon fuels into electrical energy
- Direct current output from an EMGS to a building
- Accommodations for manual disconnect switches
- Interconnection of the grounding system
- Shutoff and/or dummy-load devices for wind power generation during high winds, or when power generated exceeds requirements / storage system capacity
- Manual overrides of automatically controlled circuits
- Use of direct current by consumers directly from their EMGS
- Conversion of DC generated power into AC or for feeding excess power into a commercial power grid via an inverter or grid-interactive inverter
- Limiting harmonics that may be introduced into the electric grid by inverters
- Wiring Methods
- Overcurrent and overload protection
- Certified / listed equipment

Summary of Smart Grid Technologies-
Energy Micro-generation, Co-Generation, and Generation

NFPA Articles Affected

- NFPA 70
  - o 220.3
  - o 230.82
  - o 240.3
  - o 250.3
  - o 705.30
- NFPA 70E
  - o 100
- NFPA 110
  - o 52



herbinator.blogspot.com

THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

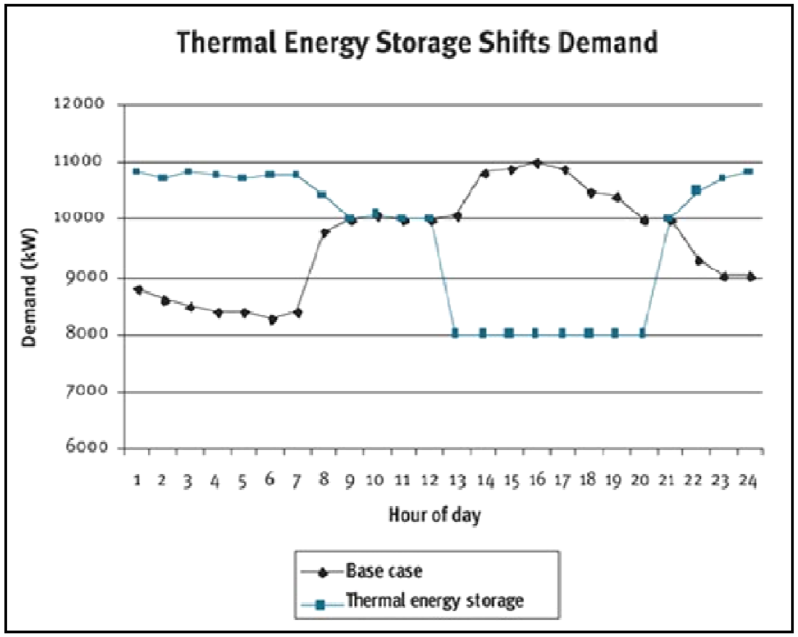
Summary of Smart Grid Technologies-
Energy Storage Systems

Description

Storage systems may be used by customers to reduce demand during peak hours, as a backup in case of grid failure, or as a way to increase the flexibility of renewable energy.

The most common types of energy storage are:

- Batteries
- Uninterruptible Power Supply (UPS) systems
- Thermal Energy Storage



energydesignresources.com

THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

Summary of Smart Grid Technologies- Energy Storage Systems

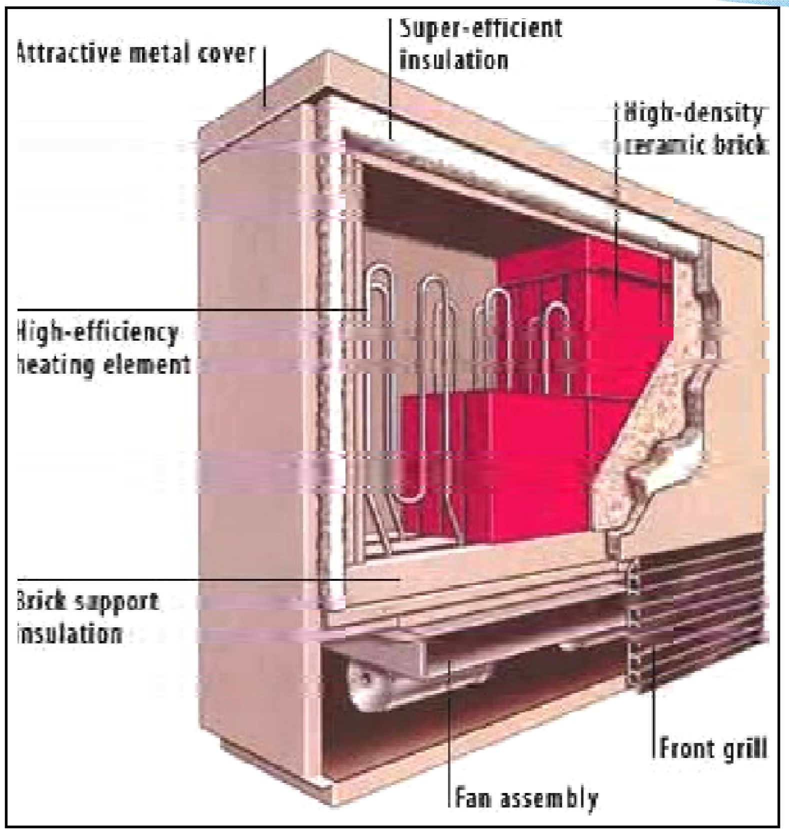
Possible NEC Issues

- Battery meter (for charging rate and voltage) installation requirements
- Protection of overcharging energy storage systems to prevent failures
- Charging and discharging of ESS
- Charge controller for charging the batteries or other energy storage
- Provisions for converting DC battery power into AC as required for many appliances, or for feeding excess power into a commercial power grid, an inverter or grid-interactive inverter
- Protection against overcharging of batteries to prevent explosions
- Guidelines for the placement of, and clearance requirements for, fuel cells
- Load & Demand factors

Summary of Smart Grid Technologies- Energy Storage Systems

NFPA Articles Affected

- NFPA 70E
  - 100
  - 120
  - 320



renovationsexpets.com

THE FIRE PROTECTION RESEARCH FOUNDATION

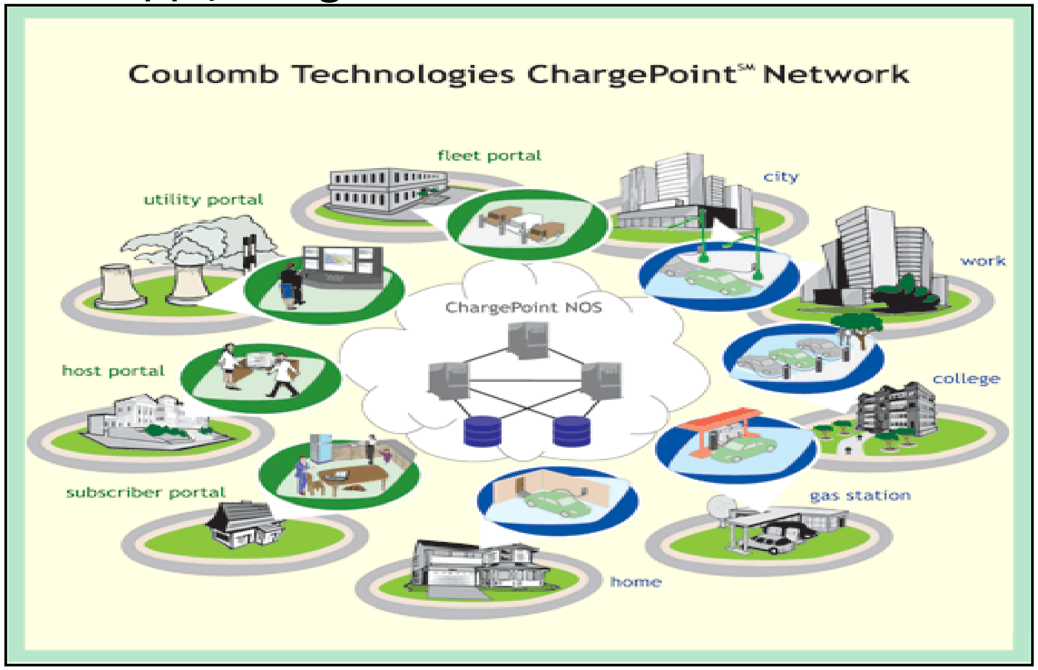
CAL POLY FIRE PROTECTION ENGINEERING

Summary of Smart Grid Technologies-
Plug-in Vehicles

Description

These vehicles have an energy storage system on-board. The storage can be charged by connection to the grid and may be able to supply the grid if needed.

Equipment includes:
- Plug-in Vehicles
- Charging EV's and Charging Stations
- Vehicle-to-Grid Storage Systems



theautochannel.com

Summary of Smart Grid Technologies- Plug-in Vehicles

Possible NEC Issues

- Battery meter (for charging rate and voltage) installation requirements
- Meters for power consumption
- Protection of overcharging energy storage systems to prevent failures
- Charging and discharging of Vehicle-to-Grid storage systems
- Charging and discharging of PHEVs, PEVs, and other on-site energy storage systems

THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

Summary of Smart Grid Technologies-
Plug-in Vehicles

NFPA Articles Affected

- NFPA 70
  - o 210.2
  - o 210.52
  - o 220.3
  - o 220.14
  - o 220.44
  - o 230.82
  - o 240.3
  - o 250.3
  - o 625.26
- NFPA 70E
  - o 100

gigaom.com

Summary of Smart Grid Technologies- Community Energy Storage & Large Switching Loads

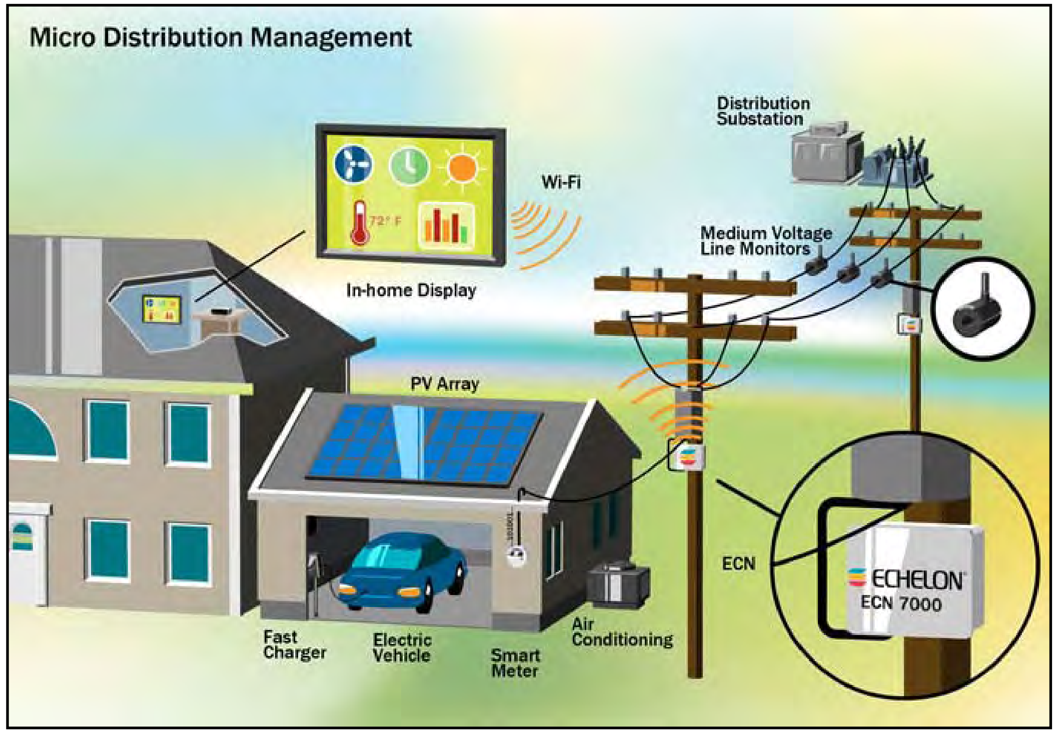
Description

A local energy storage with limited backup time that is available to a small group of customers. CES units allow excess energy from the customers to be captured and re-dispatched with less line loss then a mass-storage system located far away.

Summary of Smart Grid Technologies-
Community Energy Storage & Large Switching Loads

Possible NEC Issues

- Voltage flicker provisions
- CES unit guidelines
- CES unit placement guidelines
- Grounding and bonding provisions



echelon.com

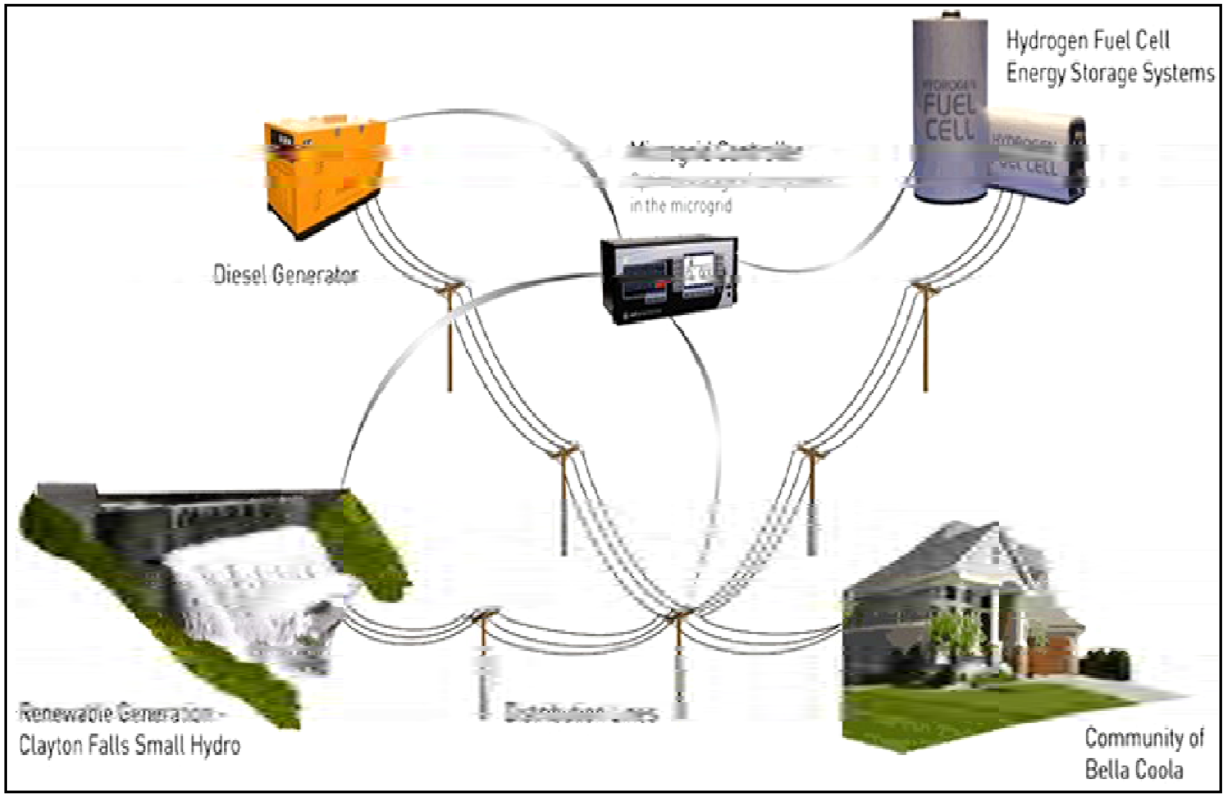
THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

Summary of Smart Grid Technologies-
Community Energy Storage & Large Switching Loads

NFPA Articles Affected

- NFPA 70
  - o 210.19
  - o 215.2
  - o 220.3
  - o 230.82
  - o 240.3
  - o 230.82
  - o 250.3
  - o 705
- NFPA 70E
  - o 100



marketwire.com

THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

Summary Matrix

Technology		Smart Meters and Energy Management					Energy Microgeneration, Generation, and Co Generation						Energy Storage Systems				Plug in Vehicles			Community Energy Storage	Large Switching Loads	Not Technology Specific
Chapter	Article	Smart Meters	EMS	Smart Plugs/ Smart Power Strips	TOU/Rate Structures	Load Shedding / Demand	Photovoltaics	Small scale wind turbine	Micro Hydro	Fuel Cells	Plant Microbial fuel cells	and Micro	Energy storage Systems	Batteries	UPS	Thermal Energy Storage	Plug in Vehicles	Charging EV's and Stations	Vehicle to Grid Storage Systems			
	90	√	√																			
2	210.2																	√				
2	210.11	√	√																			
2	210.19 (A)																				√	
2	210.52																	√				
2	215.2 (A)(4)																				√	
2	220.3							√		√								√		√		
2	220.14																	√				
2	220.44																	√				

Summary Matrix

Technology		Smart Meters and Energy Management					Energy Microgeneration, Generation, and Co Generation						Energy Storage Systems				Plug in Vehicles					
Chapter	Article	Smart Meters	EMS	Smart Plugs/ Smart Power Strips	TOU/Rate Structures	Load Shedding / Demand	Photovoltaics	Small scale wind turbine	Micro Hydro	Fuel Cells	Plant Microbial fuel cells	and Micro	Energy storage Systems	Batteries	UPS	Thermal Energy Storage	Plug in Vehicles	Charging EV's and Stations	Vehicle to Grid Storage Systems	Community Energy Storage	Large Switching Loads	Not Technology Specific
2	230.82							√														
2	240.3							√		√								√		√		
2	250.3							√		√								√		√		
4	422.31	√	√																			
4	424.19	√	√																			
4	430.75	√	√																			
4	440.11	√	√																			
4	445.18	√	√																			
4	480.5	√	√																			
5	517.31					√																

Summary Matrix

Technology		Smart Meters and Energy Management					Energy Microgeneration, Generation, and Co Generation						Energy Storage Systems				Plug in Vehicles					
Chapter	Article	Smart Meters	EMS	Smart Plugs/ Smart Power Strips	TOU/Rate Structures	Load Shedding / Demand	Photovoltaics	Small scale wind turbine	Micro Hydro	Fuel Cells	Plant Microbial fuel cells	and Micro	Energy storage Systems	Batteries	UPS	Thermal Energy Storage	Plug in Vehicles	Charging EV's and Stations	Vehicle to Grid Storage Systems	Community Energy Storage	Large Switching Loads	Not Technology Specific
6	625.26	√	√																√			
7	700.5	√	√			√																
7	701.6	√	√			√																
7	705	√	√			√															√	
7	Table 705.3							√	√		√											
7	705.20	√	√			√																
7	705.30							√	√		√											
7	705.40	√	√			√																
7	708.22	√	√			√																
7	New 750	√	√			√																

THE FIRE PROTECTION RESEARCH FOUNDATION

CAL POLY FIRE PROTECTION ENGINEERING

Research in Support of NFPA Technical Committees

WWW.NFPA.ORG/FOUNDATION

THE
FIRE PROTECTION
RESEARCH FOUNDATION