# INSTALLATION AND CONSTRUCTION MANAGEMENT ASPECTS OF SMART GRIDS: AN EMERGING BUSINESS OPPORTUNITY FOR ELECTRICAL CONTRACTORS

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**ABSTRACT**

# INSTALLATION AND CONSTRUCTION MANAGEMENT ASPECTS OF SMART GRIDS: AN EMERGING BUSINESS OPPORTUNITY FOR ELECTRICAL CONTRACTORS

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Over the past few years, there has been the realization that the current electrical grid needs to undergo major upgrades. The government, utility companies and several stakeholders have proposed modernizing the electrical grid to make it efficient to meet predicted power demands. This modernized grid is generally termed the “smart grid”.
It is evident that the growth of smart grid will require substantial development and installation efforts. These efforts will present opportunities to the construction industry, especially electrical contractors.

In order for electrical contractors to take advantage of these opportunities, they need to be conversant with technologies associated with smart grid and their installation and construction management related aspects.

This research explored smart grid smart grid technologies both in research and existing, and developed the installation work scopes and associated construction management aspects of these technologies through a work matrix. The work scope and opportunities for electrical constructors were developed from the work matrix.

To Akua and Kiran

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# CHAPTER 1

# INTRODUCTION

## 1.1. OVERVIEW

The electrical grid in the United States has been in existence since the early 1900s when power was first generated in Niagara Falls and transported to Buffalo, NY, about 20 miles away from the power source. Today, the US power grid, the largest of its kind in the world, is mostly owned by private and state entities across different states. This complex grid is made up of over 12,000 power plants, about 150,000 miles of high voltage transmission lines, millions of miles of distribution lines, more than 12,000 substations, and over 100 million customers (IEEE 2009).

Over the past few years, there has been the realization that the current electrical grid needs to undergo major upgrades. It is considered outdated for modern electricity delivery, wastes a lot of generated power, pollutes the environment and is liable to attacks from hackers, and can even serve as a way for terrorists to disrupt economic and military installations (DOE 2009a, DOE 2009c, EAC 2008, and WEF 2009).

With the recent initiatives in the United States to reduce the nation's over reliance on fossil fuels, there has been an increase in renewable energy installation over the past several years. This change is spearheaded mainly by solar and wind installations in the southeastern sun belt and in the wind corridors of the Midwest. The Energy Information Administration (EIA) Energy Outlook predicts renewable energy generation sources to represent 12.3% of total electricity generated by 2035 from the current level of 4%, an upward forecast from 11% predicted in the EIA 2008 Energy Outlook (EIA 2010). Power generated from renewable sources is intermittent in nature. The maximum power output for solar and wind is produced when there may be little demand for power (DOE 2009a). The International Energy Agency (IEA 2008) predicts the doubling of energy demand globally by 2030 as population increases worldwide and developing nations like China and India keep developing and demanding more energy for their economic growth.

In the United States and more advanced economies, the adoption of more powerful consumer electronic equipment will increase the energy demand on the electrical grid. For example, if every home in the United States adopted the use of a digital photo frame five 250MW power plants will have to be built to accommodate the demand on the grid (EPRI 2009). The EIA forecast a 30% demand in electricity by the year 2030 compared to current demand rates ((EIA2010). This increase in demand on the grid is making the grid more liable to power outages and load variations.

The government, utility companies and several stakeholders have proposed modernizing the electrical grid to make it efficient to meet predicted power demands. This modernized grid is generally termed as the “smart grid”.

A smart grid can be described as the integration of the electrical grid and the information technology/communication system so as to be able to monitor and manage the generation, storage, transmission, distribution and consumption of electricity (Austin Energy 2004). In the United States, efforts are directed towards the smart grid under two main categories:

- Upgrading of the existing transmission and distribution grid
- Creating new “smart” transmission grid for renewable energy sources

## Upgrading the Existing Transmission and Distribution Grid

Due to the enormity of the U.S. grid, the adaptation of existing grids to smart grids is being done incrementally by upgrading the existing grid to be able to generate, transport, and distribute power to consumers efficiently. The main focus of this upgrading is adding "smart" features or technologies to the existing electric grid components. The scope of this upgrade can be grouped into three main categories (DOE 2009a, EAC 2008).

- Upgrading the existing transmission grid to improve efficiency and to enhance communication with the power plants and the distribution system,
- Upgrading the existing distribution grid to efficiently connect with the transmission grid and with the consumers, and
- Upgrading information systems (e.g. automated metering devices) to enhance communication between consumers and the utilities.

## New "Smart" Transmission Grid for Renewable Energy Sources

With the United States pushing to decrease its over-reliance on fossil fuels and reduce the emission of greenhouse gases, renewable energy generation sources led by wind and solar technologies, are being adopted on commercial scales. These sources are prevalent in locations where the national transmission grid does not efficiently reach because existing grid was developed for power plants that were built near the natural resources (e.g., coal mines) used in the generation of electricity (Randolph & Masters 2008). Moreover, the existing transmission grid is not well suited for the renewable energy sources due to the intermittent generation patterns of wind and solar power generation.

## 1.2. RESEARCH NEED

The proceeding section focuses on the overview and growth of smart grid over the past few years. It is evident that the growth of smart grid will require substantial development and installation effort. These efforts will present opportunities to the construction industry, especially the electrical contractors (both line and building). With the rapid deployment of smart grids, it is imperative for electrical contractors to keep abreast of these technologies to be able to take advantage of the opportunities that the smart grid movement will bring to their businesses.

The following section will discuss the need for the proposed research with focus on the potential opportunities due to initiatives undertaken by all major stakeholders in the smart grid movement, the current and up-coming smart grid technologies, and installation and construction management aspects related to these various technologies.

### 1.2.1. Initiatives

Over the past several years, there have been numerous calls and initiatives to upgrade the electrical power systems to suit our current energy transportation and security needs. As discussed before, achieving a smart grid will include two main phases of work scope: Upgrades to the existing grid and development of new grids.

Obtaining funding for energy generation and distribution installations has been a major impediment to transmission expansion (Roseman & De Martini 2003). Utility companies have traditionally raised money from equity investors, internal cash flow and bond holders. However, after the Three Mile Island nuclear accident in 1979 and the California energy crisis in 2002 and 2003, and with its resultant bankruptcy of Enron and

Pacific Gas & Electric Company, private investment into utility related bonds have been drastically reduced. This reduction has made it difficult for significant private investments in the expansion and upgrading of the power system to meet the current power generation needs (Abel 2008, Business Week 2003). Only in recent years, the power sector has begun to experience an upward trend in bond rating (Abel 2008).

The federal government and some state governments, in an attempt to increase confidence in the energy industry and encourage investment have undertaken various initiatives (regulatory and monetary investments) towards upgrading the power grid. These initiatives include The American Reinvestment and Recovery Act (ARRA) 2009 where 3.4 billion dollars was voted for upgrading the power grid with matching funds from utility companies and industries. This represented the largest single energy investment in US history, funding a broad range of technologies to spur an increase in efficiency and foster growth of renewable energy sources and distribution (DOE 2009b).

In October 2009, the largest single electric grid modernization investment in U.S. history was announced by the Department of Energy (DOE) with $3.4 billion from The American Reinvestment and Recovery Act (ARRA). This was matched by $4.7 billion in private investments to fund 100 major smart grid projects (DOE 2009b). Examples of these projects include upgrading the distribution grids and information systems of major utility companies such as American Electric and Power (AEP), and Detroit Edison Energy (DTE Energy). The DOE also announced funding for 32 demonstration projects in November 2009 which focused on new technologies related to upgrading the electrical grid. These projects were slated to receive $620 million and matched with $1 billion private sector funding. Examples of these projects include energy-storage technologies, smart metering and distribution, and transmission monitoring equipment (DOE 2009b).

In the State of California, the State Legislature authorized the California Public Utilities Commission to set aside $50 million to help build a sustainable and self-supporting industry for customer-sited solar in California. The focus was concentrated on the following to achieve the above stated goal (CPUC 2010):

- Reducing technology costs and increasing system performance.
- Focusing on issues that directly benefit California.
- Filling knowledge gaps to enable wide-scale deployment of distributed solar.
- Supporting the integration of distributed power into the grid

With the current push to reduce the nation's reliance on fossil fuels, there has been a steady increase in the installation of renewable sources of power generation led by wind and solar technologies, with commercial wind and solar farms being installed in various locations around the country to serve the general population (AWEA 2009). The renewable energy generation forecast has been adjusted to 12.3% of the total US electricity generation output by 2035 instead of the 2008 forecast of 11% from level of 4% (IEA2008, EIA 2010, Matternetwork 2010). This upward adjustment is the result of the various renewable energy standards and initiatives continually being adopted in various states across the country (Matternetwork 2010).

Since many of these renewable energy sources are prevalent in locations where the national transmission grid does not efficiently reach and also the existing transmission grid is not well suited for the renewable energy generation and distribution due to the intermittent generation patterns of wind and solar. There is an increasing need to develop new transmission grids that can transport the electric energy produced by these renewable sources to high population centers efficiently.

### 1.2.2. Smart Grid Technologies

For the aims of grid reliability, two-way communication, efficiency etc. to be realized, a wide array of technologies will be developed and installed on the grid. Some of these technologies will be upgrades to current technologies but most will be newly developed technologies, which will be the new components on the traditional grid and change the way power is generated, transmitted and distributed to consumers.

For example, currently, generated power is consumed by households or industries in real time. Which means generation sources will have to produce more power to meet household needs in peaks periods of demand. However, when energy storage devices are introduced on the grid, generated power can be stored during period of low demand and used during times of peak demand.

### 1.2.3. Installations and Construction Management

The above discussion noted a sample of the initiatives undertaken by major stakeholders to increase the smart grid upgrade and new installations. These initiatives can lead to numerous opportunities for the development and construction industry, especially for electrical contractors. However, in order to take advantage of these opportunities, electrical contractors need to be conversant with these technologies and their installation and construction management aspects. The installation issues of the various technologies will cover, among others, changes to existing power system design, location and zoning issues, product procurement, installation issues, design and construction of support components, and time and cost issues. All the above-noted aspects have many embedded details that are different from the installation aspects of existing technologies. Therefore, with the introduction of smart grid technologies, there is a need to understand their installation aspects.

### 1.2.4. Summary

The discussions in the previous sections noted sample initiatives undertaken by various stakeholders, advancements in grid technologies and their installation aspects. These discussions point to a substantial increase in development and installation opportunities for the construction industry, with a major focus on the electrical contracting (both line and building) industry. For one to be able to understand the installation of smart grid technologies the technologies will need to be identified and changes from existing technologies will need to be highlighted. Once the various technologies are described, then the installation work scopes and associated construction management aspects of these technologies will need to be developed.

## 1.3. RESEARCH GOAL AND OBJECTIVES

The overall goal of this research is to understand the installation and construction management aspects of smart grids, with focus on the electrical construction industry, both line and building.

In order to achieve the above stated goal, the following project objectives will be attained:

1. Investigate major smart grid initiatives by major stakeholders
2. Identify and describe the various existing and emerging "smart" technologies for:
    - Existing grid upgrades
    - New grid development
3. Determine and analyze the installation and construction management aspects of the smart technologies described in objective #2 and develop a checklist of potential opportunities for the electrical construction industry.

## 1.4. RESEARCH METHODOLOGY

In this section, the objectives will be broken down into various work steps. Figure 1.1 illustrates the research methodology.

### 1.4.1. Objective 1: Investigate major smart grid initiatives by major stakeholders.

***Step 1: Compile all current and upcoming initiatives undertaken by government, investors and the power generation and distribution sector.***

These initiatives will be compiled from the information available in governments' documents, websites and utility company websites.

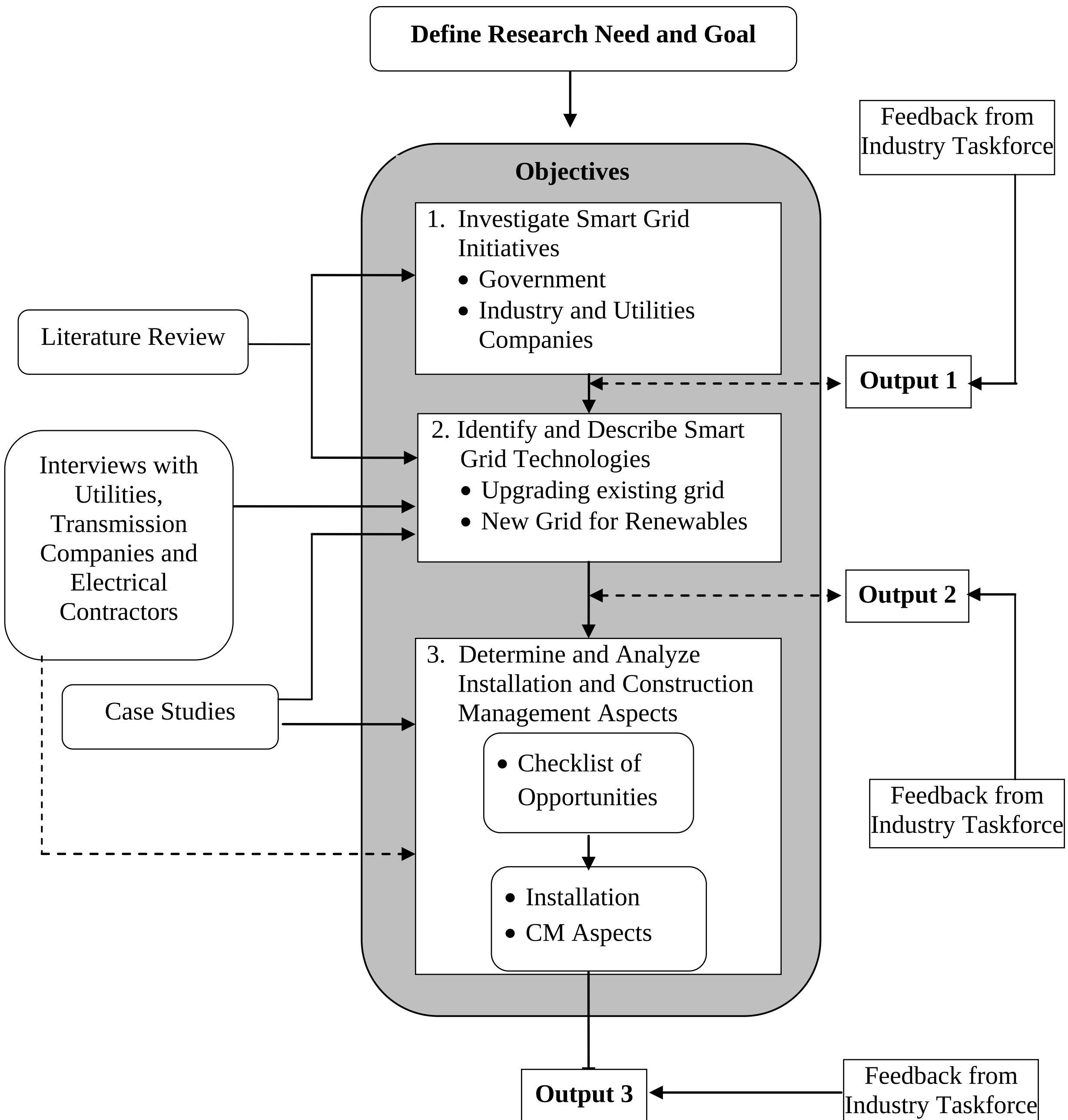



**Figure 1.1: Research Structure**

These initiatives will help project the future developments and forecasts for smart electric power grids. The main stakeholders to be covered in the literature review will be:

- Government ( federal, state and local): regulatory and investment Initiatives

- Investors (individual, mutual funds , hedge funds etc)
- Industry (utilities, generation and transmission companies , appliance manufacturers, information technology companies, etc)
- Trade Groups and Associations (e.g. National Electrical Contractors Association)

***Step 2: Analyze major initiatives for their impact on the growth of the smart grid movement and subsequently on the electrical contracting industry (both, line and building contractors.***

The initiatives in step #1 will be analyzed for their current and future impacts on the electrical constructing industry in terms of regulations and demand for smart grid installations.

***Step 3: Present the output of steps #1 and #2 to the ELECTRI -NECA industry task force for feedback.***

The initiatives identified in step#1 and their impacts analyzed from step#2 will be presented to the industry task force for input and feedback.

**1.4.2. Objective 2: Identify and describe the various existing and emerging "smart" technologies for:**

- Existing grid upgrades
- New grid development

***Step 4: Describe the technologies in the initiatives identified Objective #1 and in the literature.***

Smart grid technologies will be identified from the various initiatives described in objective#1. These technologies will be organized under generation, transmission, distribution and consumer categories. The technologies under the various technologies will be grouped into the following:

- Existing Technologies
- New Grid / Emerging Technologies

As an example, preliminary technology details of intelligent substation transformers are attempted and presented in Appendix A.

***Step 5: Conduct interviews with major transmission and distribution companies and electric contractors.***

In this step, informal interviews will be conducted with major utilities, transmission and distribution companies, and electrical contractors for technologies being investigated in this research. Appliance manufacturers, smart technology manufacturers and suppliers, and other industry sectors will also be contacted.

***Step 6: Analyze 1 or 2 Case studies and compile the work scopes.***

In this step, 1 or 2 case studies will be analyzed for all major components of the power system and the major technologies identified. In addition, work scopes of major technologies described in step #5, will be compiled from these case studies.

***Step 7: Share output and seek feedback from the ELECTRI- NECA task force.***

In this step, outputs of steps #4, #5 and #6 will be presented to the industry task force the industry task force for input and feedback.

### 1.4.3. Objective 3: Analyze and determine the installation and construction management aspects of the smart technologies described in objective #2 and develop a checklist of potential opportunities for the electrical construction industry.

***Step 8: Establish installation and construction management (CM) aspects for the technologies from objective #2.***

Using data acquired from objective #2 and electrical installations and construction management literature, construction management and installation aspects related to electrical contractors will be compiled.

The installation aspects will be categorized based on the construction work stages as follows:

1. Overall Power System Design
2. Location, Planning , Zoning and Environmental Considerations
3. Product Procurement
4. Product Installation
5. Design and Construction of Supporting Components
6. Construction Project Management

**Overall Power System Design**

Through literature, the overall power systems design will be evaluated to illustrate the changes in design due to smart components. For example, effect of new components such as renewable generation sources and energy storage devices on the power system design

**Location, Planning, Zoning and Environmental Considerations**

The location, zoning and environmental issues will cover the following:

- Location considerations and requirements adopted by city and town planners and policy makers.
- Federal, state and local government requirements for environmental approvals and permits
- Eminent domain laws
- Public perception to the installation of electric components near population centers
- Economic impact of `installations on communities.
- Financial arrangements and terms for financing smart grid installations.

**Product Procurement**

Product procurement will explore the issues pertaining to the following:

- Product availability, for e.g. whether product is commercially available, in research and development or available in limited quantities.
- Lead times for specialty product delivery, e.g. whether product if available locally, nationally, or internationally.

- Due to the sensitivity of most electrical components, the transportation options available for product delivery should be considered.
- Lastly, the lead times for specialty components will be established

**Product Installation**

Product installation aspects will include:

- Codes and standards governing the installation of the various components and technologies
- New skills and technical abilities needed including new training and certifications
- New safety procedures

**Design and Construction of Supporting Components**

Design and construction of support components will include:

- Design and factors affecting the design of supporting structures for e.g. concrete foundations; concrete piles etc.
- Existing codes and design guidelines such as. American Society of Civil Engineer Design Guides on Substation Structures,

**Construction Project Management**

Construction project management aspects will include:

- Contractual issues for e.g. contractual relationships and responsibilities,
- Project cost estimating
- Project scheduling
- Project controls
- Financial issues
- Construction safety

- Quality assurance and control

As an example, preliminary details of construction management and installation issues for procuring and installing substation transformers is provided in Appendix A.

***Step 9: Align the installation and CM aspects from step #8 with the work and business scopes of electrical contractors***

From literature review, industry interviews and case study projects a work scope matrix will be developed for electrical contractors by breaking down all the likely work processes to be undertaken into categories according to who has responsibility for completing the task. The work will be broken down into tasks to be performed by electrical contractors, tasks to be given out as subcontracts and miscellaneous tasks for undefined tasks and tasks outsourced to consultants.

***Step 10: Develop a check list outlining possible opportunities for electric contractors.***

The checklist to determine the opportunities for electrical contractors will be categorized under these main sections:

- Installation aspects
- Electrical contractors related issues
- Level of importance
- Responsibility

This checklist will be developed with the help of the following:

- Smart grid technology details from step #6
- Installation and CM issues from step #8

- Work scope of electrical contractors from step #9

Appendix C illustrates a sample overall checklist illustrating the opportunities for EC in smart grids and a sample illustration of opportunities related to the installation of a substation transformer.

***Step 11: Finalize checklist with input and feedback from ELECTRI-NECA task force members.***

The technologies scope and checklist developed in step #10 will be finalized with the help of input and feedback from the industry taskforce.

## 1.5. RESEARCH SCOPE AND LIMITATIONS

The limitations of this research are the following:

1. Informal interviews using open ended questions will be used instead of a formally structured interview.
2. The informal interview sample will be open to members of the ELETRI-NECA taskforce.
3. The phrases electric power system, power system, the electric grid and the grid will be used interchangeably.

## 1.6. DELIVERABLES

This research will attempt to identify and understand the installation and construction management aspects of smart grids with focus on the electrical contracting industry. The following research deliverables will be identified and delivered:

- Identify and document smart grid initiatives undertaken by government, utility companies, transmission companies, and investors to advance the adaptation of smart grid technologies.
- Identify and document all the major technologies relevant to smart grids
- Develop installation and construction management aspects related to installation of smart grid technologies.
- Develop a checklist outlining possible opportunities for electrical contractors.

## 1.7. DESCRIPTION OF CASE STUDIES

Several case studies were utilized for this research, these included site visits to several industry participants, reviewing project documents, interviews and discussions with industry experts and governmental agencies.

To understand electrical grids, smart grids and the electrical construction industry, preliminary visits were undertaken during the earlier part of the research. Subsequent case study visits were utilized to help develop the research outputs needed. The subsequent outputs were verified by return visits to case study participants. These preliminary outputs obtained were also further verified and refined at different stages with the help of the ELECTRI-NECA task force.

Details of the case study cases are as follows:

### 1.7.1. Overview Case Studies

**Case Study 1**

The smart grid management group of a major utilities company was interviewed. The group visited was composed of two electrical engineers with several years experience in electrical grids. The smart grid demonstration setup of the company was toured by the author. They shared their companies' initiatives on smart grids and their experiences with technologies demonstration in the pilot project.

**Case Study 2**

Six upper and middle level managers of a national utility company with various roles in the smart grid demonstration of the utility company which had won a federal smart grid demonstration grant. The team was comprised with the heads of different technological sectors in the company's smart grid demonstration. The team shared the smart grid vision of the company, and the various initiatives they were involved in.

### 1.7.2. Output Case Studies

**Case Study 3**

This was a visit to a commercial wind farm and its adjoining substation. The electrical engineer/manager of the installation shared with the author some operational difficulties and processes. The author also visited the adjoining substation to the windfarm, where the author observed some substation operations problems due to installation deficiencies.

**Case Study 4**

The operations manager of a municipal utility company with a 62kW solar installation was interviewed. The operations manager, an electrical engineer, shared operational problems with author and some operational problems based on installation and construction.

**Case Study 5**

Six top level management members of a midsized electrical construction company were interviewed. The company works in line and substation construction, tower installations, commercial inside lighting and communications. The members of the management team comprised of five electrical engineers with several backgrounds and roles. The team shared with the author the operations of the company and their professional opinions about smart grid components and the effect it will have on their business.

**Case Study 6**

This was a visit with five middle level employees of a national transmission company. The team comprised of a transmission siting specialist, transmission grid design engineer, AMI and controls engineer, construction management engineers and design and specifications engineer. The team shared on the operational processes of their various sectors and the effect smart grid was having on their operations.

**Case Study 7**

This was a visit with the AMI implementation group of a national utility company. The group comprised of an AMI engineer, the field engineer in charge of AMI component installations and the leader of the AMI group.

The group shared their experiences and difficulties in installing and AMI system on the distribution grid of the utility. The author’s second interaction with the manager of the AMI group was a review of the AMI outputs.

**Case Study 8**

A site supervisor in charge of substation construction for an electrical contractor was interviewed. The author observed the upgrade of an existing substation with the installation of smart components. The supervisor shared site practices of the substation crew, CM processes and experiences in installing substations and effects of smart components on the installation process.

**Case Study 10**

A site supervisor in charge of substation construction for an electrical constructor was interviewed. The author observed the construction of a new substation and observed the grounding procedure for a new substation. The supervisor shared CM site practices**.**

**Case Study 11**

Engineers in charge of the smart distribution and home area network of a national utility company. The managers shared their experiences with smart distribution grids and HAN implementation.. The second visit with engineering team was for verification of outputs.

**Case Study 12**

The manager in charge of smart grids section at a public utilities commission of a state was interviewed. He shared with the author the initiatives being undertaken by his office on smart grid technologies, regulatory initiatives, siting processes and problems.

**Case Study 13**

A manufacturer and installer of racks for solar panels was interviewed.

**Cases Study 14**

An estimator /project manager of a midsize electrical construction company was interviewed. The author shadowed the PM for half of a working day and was introduced to the estimating and project controls processes of the company. The PM verified outputs presented by author.

**Case Study 15**

The siting specialist of a national transmission company was interviewed. The specialist shared legislation and the process for siting and installing transmission lines. The author made two return visits were made with the specialist when the authors outputs were verified with the siting specialist.

**Case Study 16**

An electrical engineering post-doctoral fellow at a major public university, with expertise in power grid design and micro grids was interviewed. He shared the effect the various smart grid technologies will have on grid design. Verification of output was done on subsequent visits.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1. OVERVIEW

The Literature review for this research is categorized under three main sections, and the main sections are sub divided into subsections. Section 1 constitutes existing knowledge for smart grid, with emphasis on definitions, scope, goals, smart grid architecture, benefits of smart grids and projections. Section 2 focuses on smart grid technologies and Section 3 focuses on installation and construction management issues for related infrastructure projects.

**Section 1 : Smart Grid Overview**

- Smart Grid Architecture
- Benefits of Smart Grids
- Smart Grid Projections

**Section 2: Smart Grid Technologies**

- Sensing and Measurement
- Advanced Components
- Advanced Control Methods
- Integrated Communications
- Improved Interfaces and Decision Support

**Section 3: Related Infrastructure Installation and Construction Management Issues**

## 2.2. SMART GRIDS

Over the past few years there has been the realization that the current electrical grid is outdated for modern electricity delivery, wastes a lot of generated power, pollutes the environment and is liable to attacks from hackers and even terrorists. A smart grid electrical grid has been proposed as an improvement over the current grid. According to Excel Energy (2004) a smart grid can be defined as "the seamless integration of an electric grid, a communications network and the necessary software and hardware to monitor, control and manage the generation, transmission, distribution, storage and consumption of energy by any customer type." The World Economic Forum (2009) defined the smart grid to be a grid that incorporates embedded computer processing capability and two-way communications to the current electricity infrastructure and operates across the utility value chain. In other words it is the introduction of telecommunication systems into power generation, transmission and distribution to be able to enable two- way communication between the electricity source and the consumer. Even though a lot of definitions have been placed on the smart grid, a smart grid is more of a goal to be achieved that a static entity and this goal can be expressed in various ways. For the total goal of the smart grid to realized, the following should be attained (NETL 2007, ECA 2008, DOE 2009a, DOE 2009c, Miller 2009, NETL 2009 WEF 2009):

- Security and resiliency
- Reliability
- Economical
- Efficiency

- Environmentally friendliness
- Active participation by consumers
- Accommodation of various generation and storage options
- Self-healing

### 2.2.1. Architecture of the U.S. Smart Grid

Generation, transmission and distribution, have been clearly demarcated since the genesis of the power system as its main components. A smart grid comprises of two principal components, the electrical generation and transmission component and the information technology component. To implement a smart grid in the U S, the following will have to be considered as shown in figure 2.1:

- Upgrading the existing electric grid to make it suitable to transport, monitor and control generated electricity.
- Build new grids from the sources of renewable energy generation to consumers.

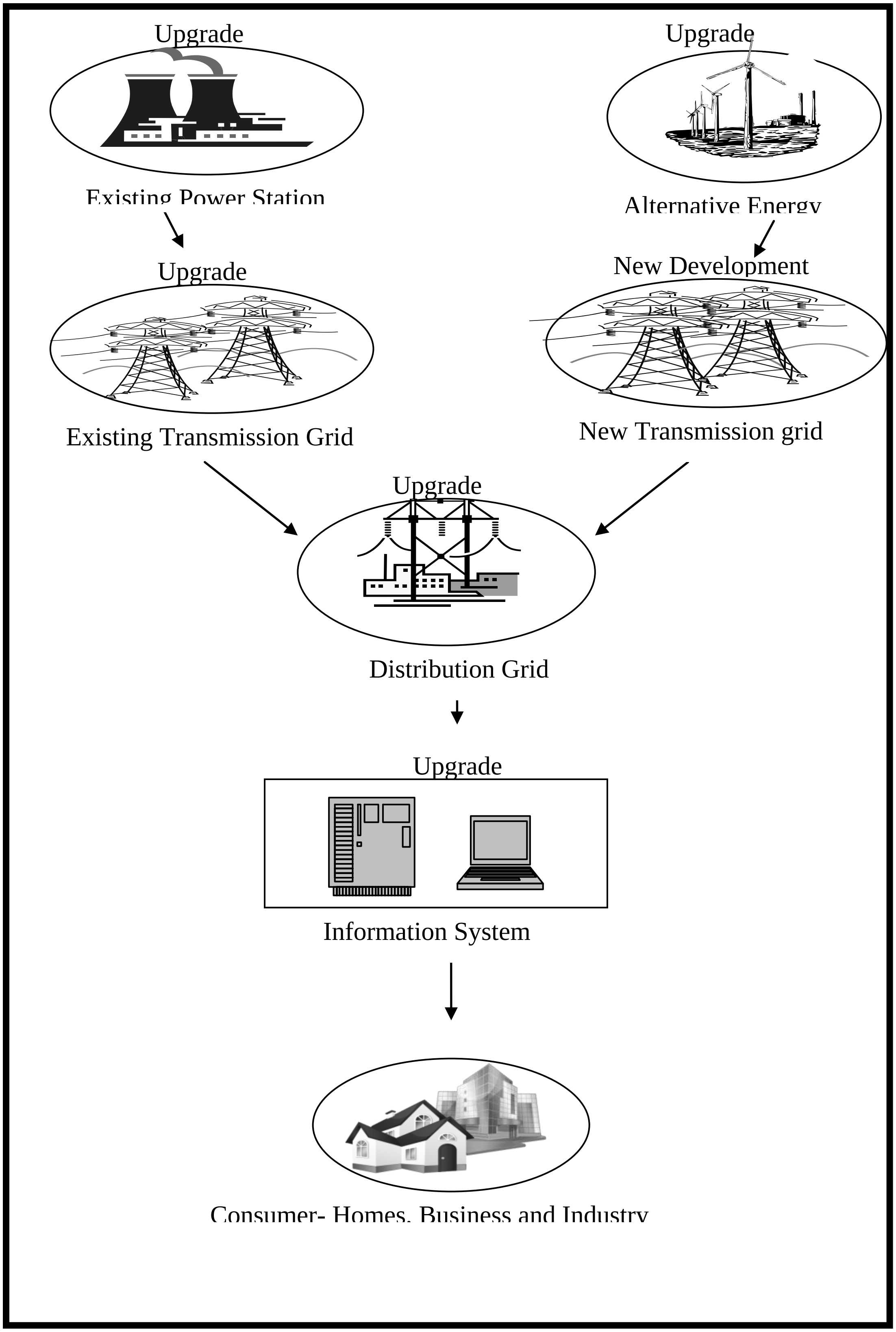



**Figure 2.1 : Smart Grid Architecture**

### 2.2.2. Benefits of Smart of Smart Grids

Several reasons have been given for the need for a new transmission grid. According to the United States Energy Information Agency (EIA 2008), there is going to be a 30% increase in U.S. electricity consumption by 2030. This is the new load equivalent to 2006 electricity usage in California, Texas, Florida, Ohio and Pennsylvania combined (EPRI 2009). Chamiedes (2009) and the Electricity Advisory Committee EAC (2008) give the reasons for a need a smart power grid follows:

- Economics and Reliability
- Benefits to Consumers
- Environmental Reasons
- Benefits to Generation, Transmission and Utility Companies

**Economics and Reliability**

Smart grids could reduce the need for direct investments in maintaining and rebuilding new generation, transmission and distribution systems to match demand from population growth (GEA 2008). According to EPRI (2003), $1.8 trillion of additional revenue will be realized from a more efficient and reliable grid. These savings can be invested into other sectors of the economy.

The power grid involves untold numbers of switches and substations connecting power plants to households and businesses whose electrical demands rapidly fluctuate in time. Unfortunately, the grid is highly sensitive to small variations in voltages. When a local failure triggers a cascade of failures, blackouts can roll across entire states – e.g. the 2003 Northeast United States Blackout which cost more than $6 billion (ELCON 2004). Such a major blackout is rare, however, short lived interruptions and fluctuations are more the norm. On paper, the power systems is 99.97% reliable, nevertheless, this is the equivalent of $150 billion of interruptions annually (GEI 2008). With an increasing digital world, even the change in power quality can cause a loss of information processes and productivity (GEI 2008). This reliability problem will deteriorate further as the power system continues to age.

To address such problems, the smart grid will be "self-healing," meaning that two way communications will help utilities to remotely detect, isolate, and fix problems in real-time with little or no human intervention (GEI 2008, Chiamedes 2009).

**Benefits to Consumers**

Current in the grid flows in a single direction – power is sent from plants to the consumer. The current grid does not monitor real- time usage by consumers or any generating contributions from micro renewable sources installed in homes. To ensure that there is enough power to satisfy all demand needs, power companies always kept excess capacity generators on hand; these extra generators usually are the oldest and most inefficient plants. Most of the electricity produced is wasted. A smart grid would interact with consumers and their smart appliances through an automated metering infrastructure, adjusting power supply and demand in real-time to maximize efficiency while guarding against system overloads (Chiamedes 2009, DOE 2009a, Faruqui et al 2009, NETL 2009). This two-way communication system made possible through the automated metering infrastructure (AMI), smart meters and the home area network (HAN) help consumers effectively manage their usage habits through automation of systems from the home. This in turn saves consumers money on energy usage, and enhances the efficiency level of the power system (EAC 2008).

**Environmental Reasons**

With the current discussion on climate change and demand on fossil fuels, there has been an intensive push by the government to reduce pollution from economic activities with minimum effect on these activities economically.

The current grid was designed for generating facilities like coal-fired plants: always operating at or near capacity. However, this assumption in design was based on a worldview of plentiful and cheap fossil energy resources, where inefficiencies and wastage were accepted as a by-product of operation (Chiamedes). Population growth, dwindling fossil fuel supplies, global climate change concerns, and security reasons demand renewable energy sources such as wind and solar. Renewable resources tend to be: spatially distributed and intermittent**,** so energy storage systems are needed to enable their continuous contribution to the non-stop electrical demands of consumers (PNNL 2002, Chiamedes 2009, DOE 2009a). Such a flexible grid would use intelligent systems to handle a wide variety of power sources and storage systems while also maintaining stability of power generated.

Implementation of smart grid could reduce emissions of gases into the atmosphere by the implementation of demand response practices. These will eliminate the generation plants used for peak supplies. These plants are usually the most inefficient and costliest to operate.

**Benefits to Generation, Transmission and Utility Companies**

The transmission system, in line with the DOE (2003) Grid Vision 2030, will enable expanded transmission and distribution of electricity from a multitude of sources, serving customers in a non-discriminatory manner (DOE 2003. Collier 2008, EAC 2008, Chiamedes 2009).Wind is most prevalent in The Midwest states of Iowa, Montana and the Dakotas, but the major population centers are concentrated on the East and West Coasts. There is therefore a need to get the - energy to these population centers with a minimum of resistive losses. As such, outmoded trunk lines will need to be replaced with single high-voltage transmission lines that cross the nation incorporating nodes along the way that allow individual sub-grids or generating stations to plug in (DOE 2003, Chiamedes 2009).

By reducing peak demand, there will be a corresponding reduction in demand for additional infrastructure. This extrapolates to a reduction in cost for building generation plants and corresponding transmission and distribution systems. Smart grid will drastically increase the efficiency of power delivery. Excel Energy (2008) estimates line loses to about 30 % of generated energy. These deferred capital investments and savings form loss prevention, will be a saving available to companies (EAC 2008).

### 2.2.3. Smart Grid Projections

Smart grid is expected to experience a gradual sustained level of growth over the next few years. According to NASDAQ (2010), estimates from research done by the Pike Group expects $53billion to be invested in smart grid technology in the US and $200 billion to be invested globally from 2008 to 2015. GTM Research (2010) expects the smart grid market to grow from 5.6 billion in 2010 to 9.6 billion in 2015. The report also anticipates a 48% national deployment of smart meters by 2015.

## 2.3. SMART GRID TECHNOLOGIES

The adaptation of smart grids culminates with the development and implementation of a wide range of technologies. These technologies will be integrated into the existing power system. The National Electric Technology Laboratory (NETL) (2007a) and (Roncero 2008) grouped smart grid technologies into 5 key technology areas (KTA). These areas are:

- Sensing and Measurement
- Advanced Components
- Advanced Control Methods
- Integrated Communications
- Improved Interfaces and Decision Support

**Sensing and Measurements**

These technologies will receive and convert operational information from components into data. Sensing and measurement technologies will check the operation quality of the individual components and the grid as a whole. The smart meter and the home area network (HAN) which are expected to enable demand response (DR) are the most widely anticipated change at the customer-end of the grid. Several wide-area monitoring systems like sag meters are being employed at the transmission ends of the grid at the utility and transmission levels. These advanced sensing measurement tools will track and transmit data to power system operators (NETL 2007b).

### Advanced Components

These technologies are components of the grid which will determine the way the grid works. The technologies will be based on advanced research and development gains in superconductivity, chemistry materials and microelectronics (NETL 2007c). Advanced components include power electronic devices like an AC/DC inverters, superconductors and energy storage devices. Advanced components are at several stages of development from research to commercially available.

### Advanced Control Methods

“Advanced Control Methods (ACM) are the devices and algorithms that will analyze, diagnose, and predict conditions in the modern grid and determine and take appropriate corrective actions to eliminate, mitigate, and prevent outages and power quality disturbances (NETL 2007d).” ACM will measure, analyze and diagnose data and autonomously respond to system faults.

### Integrated Communications

These are fully integrated two-way communication technologies that will make the grid a dynamic interactive system for power and real time data exchange (NETL 2007e, Roncero 2008). A variety of communication technologies are utilized in today’s grid but most of these lack full high speed communication integration. The integrated communication protocol will have to achieve universality, integrity, ease of use, cost effectiveness, standards, openness, and security to be most effective (NETL 2007e).

### Improved Interfaces and Decision Support (IIDS)

IIDS will be the human interface software of the smart grid. IIDS technologies will convert complicated power system data to easy to use information to aid decision making support. The IIDS will have a two-way communication capability where it might be able to send and receive data from the customer to aid decision making both at the utility and the HAN (NETL 2007f).

## 2.4. INFRASTRUCTURE INSTALLATION AND CONSTRUCTION MANAGEMENT

Literature on the installation and construction management of power systems and by extension smart grids is limited. However, construction management and installation considerations for other infrastructure developments have been considered, in this instance installing a highway project was considered due to the similarities it has with the power grid in terms being a means of spanning long stretches of land area.

**Installation and Construction Management of Highway Construction**

The development of a highway consists of four main distinct phases planning, design, construction and operation (EPA 1994, FHWA).

Planning /Preconstruction

On a highway project, the decision to build and the hiring of professionals are done during this stage. The permitting process and land acquisition is initiated at this stage. Public comments are solicited and then funding is secured.

The design idea is considered for the highway in the preconstruction stage, e.g., what highway type, number of interchanges and corridor routes are selected. The projects schedule and accompanying estimates are monitored. This stage is critical to the success of the project as it will dictate the use, appearance, construction and operational costs(Gould 1997) The destruction on the ecosystem and potential degradation is determined at this stage is also determined at this stage (EPA 1994) . According to Transtech Management (2000), larger projects take longer to plan for and complete highway projects take about 9-19 years from planning to completion (GAO 2002).

Design and Right of Way Acquisition

During this stage the siting of the right-of-way footprint is determined. The highway width, slope and types of bridges and crossing structures are determined (EPA 1994). The highway budget and schedule continue to be monitored. All structural parts of the road are finalized.

Also, during this stage citizens to be affected by construction are relocated and project cost and estimates are finalized Contract documents are developed and the bidding and contract award process undertaken to select a contractor depending on the delivery system used (Gould 1997).

Construction Phase

The actual work of construction is done during this phase; this includes vegetation removal, moving earth and road building activities. The severity of the impact on the environment (e.g., erosion and habitat disturbance) is dependent on the construction methods applied (DOE 1994).

Project Closeout, Operation and Maintenance Phase

The project completion, demobilization and all the post construction maintenance activities is categorized under this phase. The Maintenance routine including the following (Krame et al 1985; EPA 1994)

- Roadway patching and paving
- Litter collection
- Vegetation control ( e.g., mowing planting seeding etc)
- Snow removal, street cleaning and pavement marking

All these construction management and installation aspects of highway construction can adopt and modified for smart grids.

## 2.5. SUMMARY

This chapter is the compilation of the current knowledge in smart grids which is relevant to this research and will be the foundation on which outputs in the proceeding chapters will be based.

# CHAPTER THREE

# SMART GRID INITIATIVES

## 3.1. OVERVIEW

The existence and growth of smart grids is greatly influenced by various initiatives that are being introduced in recent years. Different levels of government and industry have rolled out various initiatives to support the electric grid as a whole and its various components and technologies.

The United States federal government has made the goal of upgrading the national electric grid system a matter of priority. The Energy Independence and Security Act (EISA) of 2007 define the implementation of the smart grid. There are, however, multiple challenges and issues that surround the implementation of the smart grid as identified by the ISO New England (2009).

- The Federal Energy Regulatory Commission (FERC) and the States cannot agree on how to allocate costs for smart grid investments across transmission (federally regulated) and distribution (state regulated) systems.
- The lack of consistent standards and protocols for smart grid technologies limits grid interoperability (e.g., the sense and respond (S&R) communication capabilities that are required for the automated real time control of electricity supply and demand).
- Lack of coordination among different organization and agencies has produced varying descriptions and definitions of the smart grid.

This chapter presents the vision of the smart grid by the Federal government. It then, summarizes initiatives by different levels of government, various transmission and utility companies, renewable energy generation industry, and the information technology sector related to smart grids.

## 3.2. SMART GRID VISION 2030

In 2003, the United States Department of Energy's (DOE) Office of Electric Transmission and Distribution, commissioned a committee of 65 senior executives representing the federal government, the electrical and utility industry, equipment manufacturers, information technology providers, universities, interest groups, and the national laboratories to develop a 25 year vision for the national electric grid. This vision document was named "Grid Vision 2030" (DOE 2003).

The vision of Grid 2030 is a "fully automated power delivery network that monitors and controls every customer and node, ensuring a two way flow of electricity and information between the power plant and the appliance, and all points in between. Its distributed intelligence, coupled with broadband communications and automated control systems, enables real time market transactions and seamless interfaces among people, buildings, industrial plants, generation facilities and the electric network (DOE 2003)." Simply stated, the goal of "Grid Vision 2030" is to achieve a fully functional and operational smart grid system by the year 2030. In order to achieve this goal, following three major element of the grid were considered, as shown in Figure 1 (DOE 2003):

- a national electricity "backbone"
- regional interconnections, which includes Mexico and Canada
- local distribution, mini- and micro- grids providing services to customers and obtaining services from generation sources anywhere on the continent

### 3.2.1. National Electricity Backbone

A national electricity backbone is the foundation on which the smart grid will be developed. It will consist of high-capacity transmission corridors, connecting the various states on the US mainland and also including Canada and Mexico. This national electricity backbone will enable expanded distribution of electricity from (DOE 2003):

- An efficient generation and transmission from a multitude of generation sources, and;
- A more efficient system that can adapt to seasonal and regional weather variations on a national scale.

The backbone system will include a variety of technologies including low-impedance superconducting cables and transformers operating on alternate current (AC); high voltage direct current devices forming connections between regions; and other types of advanced electricity conductors. Information, communications, and control technologies for supporting real-time operations and demand response will be included (DOE 2003).

### 3.2.2. Regional Interconnections

Power from the national electricity backbone system will be distributed over regional networks. These long-distance high transmission networks within these regional centers will be accomplished using upgraded, controllable AC systems and, in some cases, expanded DC links (DOE 2003).

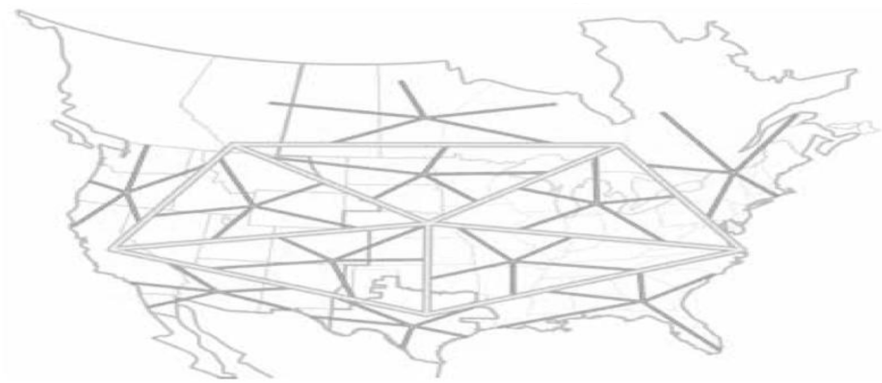
Regional transmission systems and utilities will benefit from the real time generation and consumption information transferred over the network between generation sources and the end user. The use of advanced storage devices will address demand and supply imbalances resulting from weather limitations, the intermittent supply patterns from renewable sources, and the peak demand power usage patterns of consumers (DOE 2003).

### 3.2.3. Local Distribution Grids

Local distribution systems will be connected to the regional networks and finally, to the national electric backbone. Real-time monitoring and information exchange will enable the electrical markets to process transactions instantaneously and on a nationwide basis. Customers will have the ability to tailor their individual household electricity usage to the variable rates determined by the demand response and real time monitoring of the electric system. Sensors and control systems will link appliances and equipments from inside the buildings to the utilities through the distribution system. Figure 2 illustrates a sample of the potential products and services that will be achieved under "Grid Vision 2030" and their planned timeline (DOE 2003).

**CONCEPTUAL DESIGN OF THE**
**“GRID 2030” VISION**

**National Electricity Backbone for Coast-to-Coast Power Exchange**



**Electricity Backbone Plus Regional Interconnection**

**Electricity Backbone, Regional Interconnection, Plus Local Distribution, Mini- and Micro-Grids**

**Figures 3.1: The Major Elements of Grid Vision 2030**
**(Source: DOE 2003)**

| By 2010 | By 2020 | By 2030 |
| --- | --- | --- |
| Customer "gateway" for the next generation "smart meter", enabling two-way communications and a "transactive" customer-utility interface<br>Intelligent homes and appliances linked to the grid<br>Programs for customer participation in power markets through demand-side management and distributed generation<br>Advanced composite conductors for greater transmission capacity<br>Regional plans for grid expansion and modernization | Customer "total energy" systems for power, heating, cooling, and humidity control with "plug&play" abilities, leasable through mortgages<br>"Perfect" power quality through automatic corrections for voltage, frequency, and power factor issues<br>HTS generators, transformers, and cables will make a significant difference<br>Long distance superconducting transmission cables | Highly reliable, secure, digital-grade power for any customer who wants it<br>Access to affordable pollution-free, low-carbon electricity generation produced anywhere in the country<br>Affordable energy storage devices available to anyone<br>Completion of a national (or continental) superconducting backbone |

**Figure 3.2: Grid Vision 2030 Potential Products and Services and their Timeline (Source: DOE 2003)**

## 3.3. INITIATIVES BY THE FEDERAL GOVERNMENT

Several initiatives to support the upgrading and adoption of smart grid technologies are being offered by federal, state and local governments and private industry stakeholders in the electricity generation, transmission and distribution sector. The initiatives undertaken by the federal government can be divided into two broad categories:

- Regulatory Initiatives
- Investment Initiatives

### 3.3.1. Regulatory Initiatives

To ensure a smooth transition from the existing grid to smart grid, removing bottlenecks and conflicts in the adoption of smart grid technologies has become a priority of the federal government. In order to help achieve this aim, the federal government has been pursuing regulatory policies and initiatives to encourage the investment, innovation, installation, and operation of smart grid technologies. Major regulatory policies and initiatives are:

**Energy Policy Act (EPACT) 2005**

Title II of EPACT 2005 is focused entirely on renewable energy generation. EPACT set the federal target percentages for renewable energy to 3% for 2007-2009, 5% for 2010-2012, and 7.5% for 2013 and beyond (Bluvus 2007).

**The Energy Independence and Security Act of 2007 (EISA) - Title XIII**

The Energy Independence and Security Act (EISA) of 2007 amended the Energy Policy Act 2005 by strengthening the regulatory requirements and articulated a national policy to modernize the power system with smart grid technology, authorized research and development programs, provided funding for demonstration projects and authorized matching funds for investments in smart grid technology (ISO New England 2009).

Under the EISA law, the National Institute of Standards (NIST), a unit of the Department of Commerce, was assigned to lead the development of interoperability standards for smart grid equipments and systems. Interoperability standards once developed and agreed upon, will make it easier for the manufacturers of smart components and the utility companies to develop compatible components and systems for the smooth operation of the grid. The DOE, Federal Energy Regulatory Commission (FERC) and NIST have begun interagency efforts to speed the development of these standards. NIST has created a new office of "The National Coordinator on Smart Grid Interoperability;" to push the effort of adopting interoperability standards forward (Siciliano 2009).

The NIST plan calls for establishing technical domain expert working groups responsible for developing interoperability issues and lead the technical direction.. Areas that lack or require additional standards development include (NIST 2008):

- Building-to-grid (B2G) standards
- Industrial-to-grid (I2G) standards
- Home-to-grid (H2G) standards
- Domain interfaces
- Cross-cutting issues.

A sample of the initiatives by DOE and NIST under EISA are summarized in Table 3.1.

**Table 3.1: EISA Smart Grid Initiatives and Deadlines (Modified From: ISO New England 2009)**

| Initiative | Target Date | Status | Comments |
|---|---|---|---|
| NIST develops an interoperability framework that includes protocols and model standards for information management to achieve interoperability of Smart Grid devices and systems. | February 2008 | Completed | |
| DOE establishes the Smart Grid Advisory Committee and Smart Grid Task Force. | March 2008 | Completed | |
| Smart Grid Task Force reports to Congress on the status of Smart Grid deployments nationwide and regulatory or government barriers to continued deployment. | December 2008 | Completed | |
| NIST publishes progress report on recommended or consensus standards and protocols in the interoperability framework. | December 2008 | Pending | |
| DOE publishes procedures for reimbursement of qualifying Smart Grid investments. | December 2008 | Pending | |
| DOE studies and reports on the effect of private distribution wire laws on the development of combined heat and power (CHP) facilities. | December 2008 | Pending | |
| DOE reports to Congress identifying existing and potential impacts of the deployment of Smart Grid systems on improving the security of the nation's electricity infrastructure and operating capability. | June 2009 | Pending | |
| DOE establishes a regional Smart Grid demonstration initiative that specifically focuses on demonstrating advanced technologies for use in power grid sensing, communications, analysis, and power-flow control. | **February 2010** | Pending | Demonstration programs with regional utilities under Smart grid Grants |
| DOE develops advanced R&D of power grid digital information Technology. | **None** | Unknown | |

### 3.3.2. Investment Initiatives

Obtaining funding has been a major impediment to transmission expansion (Roseman & De Martini 2003). Utility companies have traditionally raised money from equity investors, internal cash flow, and bond holders. After the Three Mile Island nuclear accident in 1979 and the California energy crisis in 2002 and 2003, and subsequent bankruptcy of Enron and Pacific Gas & Electric Company, private investment into utility related bonds reduced drastically (Abel 2008, Business Week 2003). In recent years, the power sector has begun to experience an upward trend in bond ratings (Abel 2008). The federal government and some state governments, in an attempt to increase confidence in the energy sector, and encourage investment, have undertaken various initiatives to attract investment towards upgrading the power grid.

**Energy Policy Act (EPACT) 2005**

The energy production tax credits for companies, who research and manufacture components, and invest in renewable generation plants, were extended for two more years. The Act also created clean renewable energy bonds for qualifying entities that invest in renewable energy generation (Bluvus 2007).

**The American Reinvestment and Recovery Act (ARRA) 2009**

The American Reinvestment and Recovery Act 2009(ARRA) included 3.4 billion dollars, through DOE, for upgrading the power grid with matching funds from utility companies and industry. This amount represented the largest single energy investment in US history, funding a broad range of technologies to spurn an increase in efficiency and foster growth of renewable energy sources and distribution (DOE 2009, DOE 2009d, and

Renewable Energy World 2009). The DOE grants are summarized in Table 3.2 and sample projects under each category are provided in table 3.3.

Soon after, DOE announced its second round of funding opportunities totaling $100 million for transformational energy research projects through its Advanced Research Projects Agency-Energy (ARPA-E). In this round of funding, projects focused on Smart Grid technologies research in biofuels, carbon capture and electric vehicle batteries (Smartgridnews 2010).

**Table 3.2. ARRA Project Breakdown Summary (Adopted From: DOE 2009, DOE 2009d, and Smartgridnews 2010)**

| **ARRA Project Summary** |
|---|
| - Smart Grid Investment Grant Program; 3 years $3,400 million<br>• Smaller projects, $300K-$20M; 40% of funding<br>• Larger projects, $20M-$200M; 60% of funding<br><br>The funds were awarded in 6 broad categories namely:<br>• Advanced Metering Infrastructure AMI<br>• Customer Systems<br>• Electric Distribution Systems<br>• Electric Transmission Systems<br>• Equipment Manufacturing<br>• Integrated and/or Crosscutting Systems |
| - Smart Grid Demonstrations Program; 3-5 year $700million<br>• Regional Demonstrations, up to $100M per project<br>• Grid-scale Energy Storage Demonstrations |
| - Grid-scale Energy Storage Demonstrations |
| - Resource Assessment and Interconnection-Level Transmission Analysis and planning $80 million |
| - State Electricity Regulators Assistance $50 million |
| - Enhancing State Government Energy Assurance Capabilities and Planning for Smart Grid Resiliency $55 million |
| - Workforce Development $100 million |
| - Interoperability Framework Development by NIST $10 million |

**Table 3.3 - Sample American Recovery and Reinvestment Act Projects (Adopted From: DOE 2009, DOE 2009d, and Smartgridnews 2010)**

| ARRA PROJECT BREAKDOWN | | | | |
|---|---|---|---|---|
| **Name Of Awardees** | **Recovery Act Funding Awarded** | **Total Project Value Including Cost Share** | **Headquarters Location** | **Brief Project Description** |
| **1** | **2** | **3** | **4** | **5** |
| **Advanced Metering Infrastructure (AMI)** | | | | |
| − Center Point Energy | $200,000,000 | $639,187,435 | Houston, TX | Install 2.2 million smart meters. Install 550 sensors and automatic switches. |
| − Sioux Valley Southwestern Electric Cooperative Inc | $4,016,368 | $8,032,736 | Coleman, SD additional benefits in MN | Install 23,000 smart meters to all customers |
| **Customer Systems** | | | | |
| − Honeywell International Inc | $11,384,363 | $22,768,726 | Danvers, MA | Provide automated peak price response for almost 700 commercial and industrial customers |
| − Iowa Association of Municipal Utilities | $ 5,000,000 | $12,531,203 | Akeney, IA | Broad based load control and dynamic pricing program by 75 consumer owed utilities serving 96,000 customers in three states. |
| **Electric Distribution Systems** | | | | |
| − Consolidated Edison Company of New York, Inc | $136,170,899 | $272,341,798 | New York, NY with additional in NJ | Deploy wide range of grid- related technologies, including automation, monitoring, and two-way communication to enable integration with renewable sources |
| − Powder River Energy Corporation | $2,554,807 | $5,109,614 | Sundance, WY | Develop a new, secure communications and data network through utilities service territory |
| **Electric Transmission Systems** | | | | |
| − Western Electricity Coordinating Council | $53,890,000 | $107,780,000 | Salt Lake City, UT additional benefits in AZ, CA,CO, ID,MT, NM, NV, OR, SD, TX and WA | Install over 250 phasor measurement units across the Western Interconnection and create a communication system to collect data for real time awareness. |

**Table 3.3. Sample American Recovery and Reinvestment Act Projects (Adopted From: DOE 2009, DOE 2009d, and Smartgridnews 2010) (Continued)**

| | 2 | 1 | 4 | 5 |
|---|---|---|---|---|
| – Midwest Independent Transmission System Operator | $17,271,738 | $34,543,476 | Carmel IN, with additional benefits in IA, IL, MI, MO, MT, ND, OH, PA, SD and WI | Install, test , integrate and monitor 150 phasor measurement units in strategic locations across the Midwest on independent transmission operators. |
| **Equipment Manufacturing** | | | | |
| – Whirlpool Corporation | $19,330,000 | $38,681,000 | Benton Harbor, MI | Support the manufacture of smart appliances to accelerate the commercialization of residential appliances capable of communicating over a home network with other smart technologies. |
| – Georgia System Operations Corporation Inc | $6,456,501 | $12,913,003 | Tucker, GA | Upgrade computer systems to instantaneously and automatically communicate information about disruptions or changes in flow on the grid. Use digital controls to manage and modify electricity demand |
| **Integrated and Crosscutting Systems** | | | | |
| – Duke Energy Business LLC | $200,000,000 | $851,700,000 | Charlotte, NC with additional benefits in IN and OH | Comprehensive grid modernization for Duke's Midwest electric system encompassing OH, IN and KY. Includes installing open, interoperable, two-way communications networks, deploying smart meters, automating advanced distribution applications and support for plug in electric vehicles. |
| – Detroit Edison Company | $83,828,878 | $167,657,756 | Detroit, MI | Smart Currents program includes deploy a large scale network of 660000 smart meters, implement the SmartHome program which will provide dynamic pricing and smart appliances to customers and SmartCircuit to improve grid distribution operations through circuit upgrades. |

**Emergency Economic Stabilization Act of 2008.**

In the Emergency Economic Stabilization Act of 2008, the depreciation period for smart grid meters and other grid equipments as specified in the EISA Act of 2007, was reduced from 20 years to 10 years. The value of this tax change to the power industry is reportedly $915 million over 10 years (EAC 2008, Kaplan 2009).

**Tax Incentives**

There have been several tax credits and incentives passed by the U.S. Congress to encourage the investment and adaptation of renewable energy generation. Table 3.4 summarizes some of the tax credits/incentives enacted for renewable energy producers and smart grid technology (DSIRE 2010).

**Table 3.4 – Sample Federal Tax Credits/Incentives (Source: DSIRE 2010)**

| Credit | Incentive Type | Applicable Sector | Remarks |
|---|---|---|---|
| Renewable Electricity Production Tax Credit | Corporate Tax Credit | Renewable Generation | http://www.irs.gov/pub/irs-pdf/f8835.pdf |
| Modified Accelerated Cost-Recovery System (MACRS) + Bonus Depreciation (2008-2009) | Corporate Depreciation | Renewable Generation | 26 USC § 168 |
| US DOE Agriculture Rural Energy America Program (REAP) Loan Guarantees | Rural Renewable Generation | Renewable Generation | http://www.rurdev.usda.gov/rbs/busp/bprogs.htm |
| U.S. Department of Energy - Loan Guarantee Program | Federal Grant Program | Energy efficiency, renewable energy and advanced transmission and distribution projects | http://www.lgprogram.energy.gov |

## 3.4. INITIATIVES BY STATE GOVERNMENTS

Several state governments have enacted laws to encourage the adoption of smart grid technologies and renewable energy generation sources. Most of these states have also adopted Renewable Energy Portfolio Standards (REPS), stipulating all utility companies to acquire a set percentage of their distributed electricity from renewable sources by a certain future time (AWEA 2010). According to a *smartgridnews.com's* survey of the "smartest" states (Smartgridnews 2010), California came out as the state with the most well defined combination of policy initiatives and potential. In addition, California utilities such as, Southern California Edison (SCE), is undertaking a smart grid demonstration project and installing smart meters to all its customers through the American Reinvestment and Recovery Act (Berst 2009). Texas, Ohio and states in New England also came up for special mention. Almost all 50 states have some form of legislative initiatives related to renewable energy and energy efficiency that are either being worked on or have already passed into law. Below are some of the major initiatives in key states.

### 3.4.1. California

**SB 837 (Florez) Smart Grid Technologies (Introduced in January 2010)**

This bill states the intent to enact legislation to ensure that the electrical companies, authorized to deploy smart grid technology including smart meters, are meeting their intended goals and have not shifted unnecessary deployment costs onto consumers. (Florez 2010)

**AB 2514 (Skinner) Energy Storage Portfolio Standard (Introduced in February 2010)**

This bill would require each electrical utility, as of January 1, 2014, to procure new energy storage systems that can provide specified percentages of the utility's average peak electrical demand using stored energy that was generated during off-peak periods of electrical demand. The bill would also require each electrical utility to develop plans to meet the energy storage portfolio procurement requirements and to report certain information to the State Energy Commission (Skinner 2010).

**SB 17 (Padilla) – Electricity: smart grid systems. (2009)**

This bill requires, by July 1, 2010, the California Utilities Commission, in consultation with the State Energy Commission and other key stakeholders, to determine the requirements for a smart grid deployment plan. It requires each electrical utility, by July 1, 2011, to develop and submit a smart grid deployment plan to the commission for approval. The bill also authorizes for the deployment of smart grid products, technologies, and services by entities other than the electrical utilities (Padilla 2010).

**The California Solar Initiative Research, Development, Demonstration and Deployment (RD&D) Plan (2010)**

This plan authorized the California Public Utilities Commission to set aside $50 million to help build a sustainable and self-supporting industry for customer-sited solar energy installations.. In order to achieve the above-stated goal, following areas were emphasized (CPUC 2010):

- Reducing technology costs and increasing system performance.
- Focusing on issues that directly benefit California.
- Filling knowledge gaps to enable wide-scale deployment of distributed solar.
- Supporting the integration of distributed power into the grid

As part of this plan, the California Public Utilities Commission (CPUC) has begun the rulemaking process to consider policies for investor-owned electrical utilities to develop a smarter electric grid in the state. The process will consider setting policies, standards and protocols to guide the development of a smart grid system and to facilitate integration of new technologies such as, distributed generation, storage technologies, and electric vehicles. Samples of projects funded under the California Solar Initiative are illustrated in Table 3.5 (CPUC 2010).

**Table 3.5: Major Projects in CA Solar Initiative (CPUC 2010)**

| Applicant | Proposal title | Funding Request | Match Funding |
|---|---|---|---|
| Sacramento Municipal Utility District | High Penetration PV Initiative | \$2,968,432.00 | \$1,293,259.00 |
| Clean Power Research | Advanced Modeling and Verification for High Penetration PV | \$976,392.00 | \$2,293,000.00 |
| National Renewable Energy Laboratory | Beopt-CA (EX): A Tool for Optimal Integration of EE/DR/ES+PV for California Homes | \$985,000.00 | \$329,000.00 |
| kW Engineering | Specify, Test and Document an Integrated Energy Project Model | \$942,500.00 | \$250,000.00 |
| National Renewable Energy Laboratory | Analysis of High-Penetration Levels of PV into the Distribution Grid in CA | \$1,600,000.00 | \$1,400,000.00 |
| APEP/UC Irvine | Development and Analysis of a Progressively Smarter Distribution System | \$300,000.00 | \$100,000.00 |
| SunPower Corporation | Planning and Modeling for High-Penetration PV | \$1,000,000.00 | \$320,000.00 |
| University of California San Diego (UCSD) | Improving Economics of Solar Power Through Resource Analysis, Forecasting and Dynamic System Modeling | \$548,148.00 | \$137,037.00 |
| | **Total** | **\$9,320,472.00** | **\$6,122,296.00** |

### 3.4.2. New England States

Several States in New England have adopted policies and enactments to encourage smart grid adoption. Table 3.6 summarizes some of the major initiatives (ISO New England 2009).

**Table 3.6 - Smart Initiatives in New England (Modified from: ISO New England 2009)**

| State | Description | Scope | References |
|---|---|---|---|
| MA | The Massachusetts 2008 Act Relative to Green Communities, signed into law July 2008, | Mandates for Utilities to file plans for Smart Grid pilot projects by April 2009 | http://www.mass.gov/legis/laws/seslaw08/sl080169.htm |
| RI | Rhode Island Senate Bill S 2851 | Implement smart meters and to demonstrate smart grid implementation | http://www.rilin.state.ri.us/BillText08/SenateText08/S2851Aaa.pdf |
| NH | Southern New Hampshire University is testing a real time controller for PHEVs that can respond to price signals from the five-minute electricity grid spot market. | The vehicles will make money selling power into the grid during high-load conditions by responding to five minute spot market price signals, for example, $0.25/kilowatt-hour (kWh) | May 9, 2008 http://www.nhbr.com/apps/pbcs.dll/article?AID=/20080509/INDUSTRY17/437649673/-1/Industry17 |
| CT | Connecticut Light and Power currently is engaged in an advanced metering infrastructure project | Smart meter infrastructure | http://www.amraintl.org/symposium/2007Papers/Papers/4EScott.pdf |
| CT | Connecticut announces the Solar Lease program. August 20, 2008 | Help low- and moderate-income residents acquire photovoltaic solar power systems. | www.sustainablebusiness.com/index.cfm/go/news.display/id/16603 |

## 3.5. INITIATIVES BY LOCAL GOVERNMENTS

Several cities and counties have also taken initiatives to promote smart grids. For example, in 2008, Excel Energy, a utility company in Colorado, in conjunction with the city of Boulder Colorado, initiated a 5 year citywide smart grid implementation pilot program. This pilot project will include smart grid components in the distribution and consumer networks (Excel Energy 2008). Similarly, the city of Austin, TX, is collaborating with the Austin Energy to set up a smart grid project (Burkhalter 2008).

## 3.6. INITIATIVES BY THE TRANSMISSION COMPANIES

### Electric Power (AEP) Transmission Company

American Electric and Power (AEP), a shareholder-owned utility company, has outlined plans to build a new 765-kilovolt (kV) transmission line stretching from West Virginia to New Jersey. The proposed transmission superhighway would span approximately 550 miles. It is designed to reduce congestion costs in the regional transmission by substantially improving the ability to transfer electricity from West to East. The transfer capability will improve by approximately 5,000MW when completed and the projected investment will be about $12 billion by 2013 (EEI 2005, AEP 2006).

### ITC Holdings

ITC Holdings, an electricity transmission company, is developing a 12,000-megawatt transmission network to transport renewable energy from wind farms in the Midwest to large population centers like Chicago and Minneapolis. This initiative, known as the “Green Power Express” will add about 3,000 miles of high-voltage transmission lines across parts of North Dakota, South Dakota, Minnesota, Iowa, Wisconsin, Illinois and Indiana. The project is estimated to cost between $10 billion to $12 billion. (Greenbang 2009). Other subsidiaries of ITC Holdings, namely ITC transmission, ITC

Midwest and ITC Great Plains are pursuing similar projects in their respective regions of operations (ITC 2009).

### 3.7. INITIATIVES BY EQUIPMENT MANUFACTURERS

Many equipment manufacturers and related industry associations have taken steps to promote the smart grid. Following are some key initiatives:

- The National Electrical Manufacturers Association (NEMA) announced the completion of SG-AMI 1-2009-Requirements for Smart Meter Upgradeability, the first Smart Grid standard. This standard provides guidance to utilities and state commissions on the procurement of automated metering infrastructure (AMI) systems (NEMA 2009).
- Whirlpool Corp., in April 2009, announced that their appliances will be smart grid compatible by 2015. They also set a goal of producing 1 million smart dryers by 2011. Similar steps are being taken by other manufacturers including GE (Greenbeat 2009, Gunther 2009).
- Honeywell Company was one of four non-utility companies to receive funding through the America Recovery and Reinvestment Act. Honeywell will use the grant to support a critical peak pricing response program that will help commercial and industrial facilities in the Southern California Edison (SCE) service territory to automatically implement energy management strategies (Honeywell 2010).

## 3.8. INITIATIVES BY UTILITY COMPANIES

Several utility companies are taking advantage of the matching funds from the America Recovery and Reinvestment Act (ARRA) grants awarded through DOE. For example, Columbus Southern Power Company, doing business under the name of AEP Ohio, has secured a matching federal grant of $75 million to establish the AEP gridSMART demonstration Project. The aim of the project is to demonstrate a secure interoperable and integrated smart grid infrastructure for 110,000 consumers, which will maximize distribution system efficiency and reliability, and enable consumers to reduce their energy use. It will include 13 different technologies from the substation to the customer, including distribution automation and control, battery storage, smart appliances, home area networks, plug-in hybrid electric vehicles, and renewable generation sources. These technologies are estimated to improve the reliability and efficiency of the distribution system by 30-40% (DOE 2009).

Several other utility companies have smart grid initiatives on different scales over the country. Austin Energy in Texas, Southern California Edison in California, and Oncor and Centerpoint in Texas, has large scale smart grid demonstrations (DOE 2009). In addition, many utility companies have undertaken non-ARRA initiatives, e.g., those described under the sections on initiatives by state and local governments.

## 3.9. INITIATIVES BY RENEWABLE ENERGY INDUSTY

Most initiatives by the renewable energy industry will directly or indirectly impact the smart grid movement. The growth of new wind and solar energy installations will particularly influence the growth of new smart transmission grid. According to the

American Wind Energy Association, the current capacity of wind generated electricity is around 35000 MW but major projects are underway that will add substantially to this figure. For example, British Petroleum is developing about 100 wind farm projects at different phases of construction and operation that will generate 20,000 MW of electricity after completion in five states. There are several major projects similar to these under construction around the country. (AWEA 2010, BP 2009).

## 3.10. INITIATIVES BY THE INFORMATION TECHNOLOGY INDUSTRY

In recent years, many information technology companies of all sizes have forayed into smart grid technologies. For example, Intel Corporation, in January 2010, came out with a Home Energy Management concept as a user interface for homes. This device will allow one to integrate thermostat functions, energy management tools, home security monitoring, and other functions such as home network management, task reminders, and video memos (Zheng 2010). Apple Inc., another major IT company, has recently jumped into the home energy management arena. The company has applied for patents for a home energy management system that would allow consumers to reduce electricity bills by controlling and maximizing how power is allocated to home electronics .The two Apple patent applications, Intelligent Power Monitoring and Intelligent Power-enabled Communications, were filed in May 2009 (Smartgridnews 2010). Google has also introduced its free home energy management software called, Googlemeter and, Microsoft has introduced its own energy management software called Hohm, which is the software used by Ford on its hybrid vehicles (Dignan 2010).

## 3.11. SUMMARY

This chapter summarized the national vision for the smart grid and the various initiatives undertaken by government at all levels and by industry. These initiatives illustrate the roadmap to the future for the electric grid and demonstrate that smart grids are going to be a recurring source of opportunities as the grid infrastructure age and demand for energy continue to increase over the coming years. These initiatives also highlight the multi-facetted nature of the smart grid movement, along with various financial incentives and the sectors in which these incentives are promoting business opportunities.

# CHAPTER 4

# SMART GRID TECHNOLOGIES

## 4.1. OVERVIEW

This section will explore both the upcoming and the existing major smart grid technologies. These technologies have been grouped into five broad categories by the National Energy Technology Laboratory (NETL). An overview of each technology and its location on the grid will be considered, followed by its development status and existing installations, if any, that are available.

## 4.2. INTRODUCTION

In order to understand the various smart grid technologies discussed in this chapter, the section presents a brief introduction of the power system. The electric power system consists of three distinct component parts:

- Generation
- Transmission
- Distribution

In between these main components are the step-up and step-down substations, which ease the transportation of electrical power over long distances (Figure 4.1).

**Power Generation**

The power generating plant is the foundation of the electric power system. A power system will consist of several generation stations, distributed over a large area, operating simultaneously to keep a power balance in the grid (Schavemaker and Van Der Sluis 2008). When the national grid was started about a century ago, power plants were built near the natural resources used in electricity generation. These were mostly in the cold industrial centers, near coalmines. By 2008, coal accounted for almost 40% of the total electricity produced in the US, with nuclear at 19%, natural gas at 21%, hydroelectric at 6% and non-hydro renewable energy accounting for 3% (EIA 2010).

Alternate sources of energy are prevalent in locations where the national electric grid does not efficiently reach, and the intermittent generation patterns of wind and solar mean that the existing grid is not well-suited to alternative energy delivery. As such, with the advent of alternative energies like solar and wind power, a grid needs to be built that is suited to these forms of energy; to transport the alternative energy produced to large population centers.

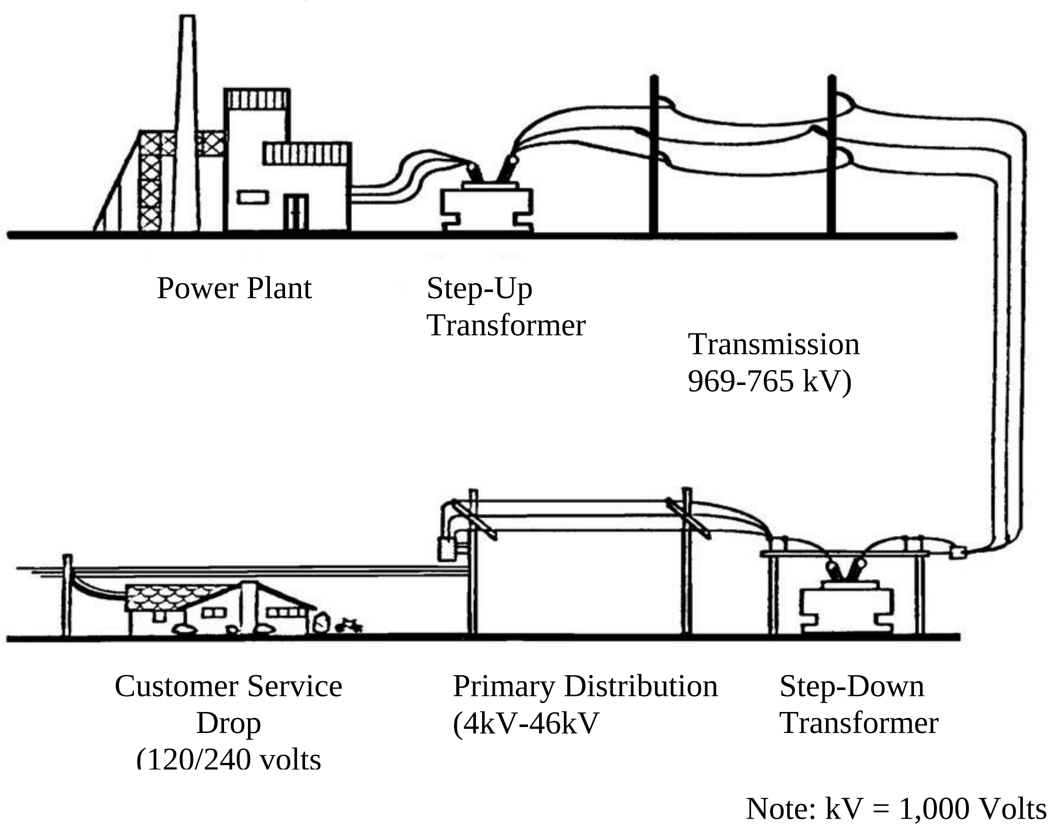



**Figure 4.1: Components of the Electrical Grid (Source: PSC of Wisconsin 2009)**

## Renewable Power Generation

The term "renewable energy" refers to energy derived from a broad range of resources, all of which are based on naturally renewing energy sources such as sunlight, wind, flowing water, the earth's internal heat, and biomass (Bull 2000). These resources can be used to produce electricity for all economic sectors.  Hydroelectric dams account for about 6% of total US electricity, and comprise the largest renewable energy source in the world. Currently, however, renewable sources of energy refer mainly to non-hydro sources of renewable energy, e.g. solar, wind and geothermal.

Renewable energy sources account for about 3% of the total electricity in the US. The adoption of renewable energy is still in its formative stages. Government initiatives, together with more advanced and efficient technologies, are encouraging a rapid adaptation to renewable energy.

## Transmission Substation

Transmission substations connect two or more transmission lines. These substations contain high-voltage switches that allow lines to be connected or isolated for maintenance, and shut down without interrupting power supply. A transmission station may have transformers to convert between two transmission voltages, or equipment such as phase angle regulators to control the power flow between two adjacent power systems. Transmission substations can range from simple to complex. The largest transmission substations can cover a large area with multiple voltage levels, as well as a large amount of protection and control equipment (capacitors, relays, switches, breakers, and voltage and current transformers) (USDA 2002).

Transmission substations also serve as a protector of the power system. In substations, protector equipment, like voltage transformers, current transformers and protective relays are installed, together with circuit breakers and disconnectors, to perform switching operations. The system is also grounded at the substations (Schavemaker and Van Der Sluis 2008).

**Transmission**

High voltage transmission lines are a more efficient means of transporting power over long distances than low voltage distribution lines. All transmission voltages above 69kV is considered transmission; it is referred to as distribution when it is lower than 69kV.

Transmission lines use shield wires to protect the lines from lightning conditions. The shield wires are sometimes called static wires or earth wires. The shield wires are bare and connect the transmission pole to the earth. The shield wires are usually the highest wires on the transmission pole (Blume 2007).

**Distribution**

Distribution systems operate at 12.5v-24.5v, and deliver power from transmission systems to consumers (Blume 2007, Brown 2009). The distribution networks begin at the distribution transformers. Utilities control most of the distribution of electricity. Like the transmission systems, distribution systems have congestion problems.

**Consumers**

Electric consumption encompasses the energy utilized in transporting and delivering energy, including losses and waste from heating. The consumption can be divided into residential, commercial-industrial and very large energy consumers (Blume 2007).

The adaptation of smart grids will culminate with the development and implementation of a wide range of technologies. These technologies will be integrated into the existing power system. The National Electric Technology Laboratory (NETL) 2007a and Roncero 2008 grouped smart grid technologies into 5 key technology areas (KTA). These areas are:

- Advanced Components
- Sensing and Measurement
- Advanced Control Methods
- Integrated Communications
- Improved Interfaces and Decision Support

## 4.3. ADVANCED COMPONENTS

These technologies are components of the grid, which will determine the way in which the grid will work. The technologies will be based on advanced research and development gains in superconductivity, chemistry materials and microelectronics (NETL 2007c). Advanced components will include power electronic devices like AC/DC inverters, superconductors and energy storage devices. Advanced component development is at several stages of development, from research to commercially available. This section reviews the following advanced components:

- Energy Storage Devices
- Advanced Superconducting Transmission Cables

- Grid-Tied Invertors
- Smart Meters
- Demand Response Load Control Receivers
- Plug-in Hybrid Electric Vehicles and Electric Vehicles
- Electric Charging Stations

Each of the above technologies will be discussed, introducing the technology with an overview, its location on the grid, its deployment and existing installations.

### 4.3.1. Energy Storage Devices (ESD)

Large -scale stationary applications of electric energy storage (ESD) can be divided into three major functional categories (EAC 2008 Gomez et al 2010) :

- Power quality applications
- Bridging power
- Energy Management

High-power ESD applications are usually very short-term applications, lasting a second or less, and are related to maintaining the quality, reliability and security of power systems. Capacitors, flywheels, superconducting magnetic energy storage (SMES), and other similar storage devices are usually utilized for high power storage systems (Gomez et al, 2010).

In bridging power applications, energy storage systems are deployed for anywhere from a few seconds to minutes, to assure continuity of service when switching from one source of energy generation to another (ESA 2009).

For energy management needs, ESDs are deployed from several minutes to hours, to support distributed energy generation or load variations. It can also be applied for the uninterruptible power supply (UPS) or energy management needs of consumers and power suppliers.

Depending on the applications used in power systems, the storage capacity can vary from less than 1 kW to 1 GW. Pumped hydro, Compressed Air Energy Storage (CAES) and SMES are utilized for large capacities—from tens of MW up to hundreds of MW—as opposed to capacitors, different types of batteries, and fly wheels, which usually range from 10 MW down to several kW (Gomez et al 2010). Several storage technologies are in different phases of development, and those on the market are constantly undergoing improvements in capacity and longetivity.

**Sodium Sulfur (NaS) battery**

This technology is an advanced electrochemical storage system that was developed in Japan, and which has been in demonstration and use in Japan over the past decade (EPRI 2006). The NaS battery operates at about 300°C, employing an electrochemical reaction between sodium and sulfur. Molten sulfur at the positive electrode and molten sodium at the negative electrode are separated by a solid beta alumina ceramic electrolyte. The basic NaS battery has a capacity of about 50 kW and is about 89% efficient (ESA 2009, EPRI 2007b3). A 1MW capacity battery will weigh approximately 88 tons and be equivalent to the size of two semi-trailers. The batteries have a lifespan of at least 15 years, assuming 2,500 charge/discharge cycles (OE 2009).

The total installation is expensive, in relation to similar storage technologies, due to the cost of a backup generator, which is needed to keep the battery hot at all times, in the event of a major outage on the grid. The need to maintain high NaS battery temperatures also has an impact on its efficiency, due to total parasitic losses. This is not the case, however, if the battery is utilized daily. The battery cells are usually arranged in blocks, to provide a more efficient heat conservation rate, and the cells are stored in vacuum-insulated boxes, with sand insulation serving as packaging (OE 2009).


**Figure 4.2 – NAS Battery Station Installed for a Wind Farm (Source NGK 2010b)**

<u>Location on Grid</u>

NaS batteries are located on the distribution feeder of a power system. However, several companies plan to apply NaS technology to the generation side of the power system (Nanomarkets 2009).

<u>Deployment Status and Existing Installations</u>

NaS batteries have been deployed at several sites in Japan, with 6 hours daily peak shaving provided by 270 MW of stored energy. In the U.S., utilities have deployed 9 MW for peak shaving, backup power, firming wind capacity and other applications;

several NaS projects are now in progress that will allow for 9 MW of storage (ESA 2009, EPRI 2007b, Lindley 2010).

America Energy and Power (AEP), headquartered in Ohio, was the first US Company to deploy NaS Technology on a commercial basis, by deploying and operating a demonstration unit in 2002. In 2006, AEP installed a 1.2 megawatt (MW) stationary NaS battery near Charleston, W.Va. AEP and other utilities plan to install more than 1,000 MW of distributed energy storage on the grid by 2020 (Nourai 2007).

**Compressed Air Energy Storage (CAES)**

In compressed air energy storage (CAES), off-peak or excess electricity from wind energy or nuclear plants is used to "pre-compress" air, which is stored in an underground cavern—usually a salt cavern or deserted mine. In times of peak demand, the CAES plant regenerates the stored power. The compressed air is released from the cavern and heated through a recuperator, before being mixed with natural gas and forced through a turbine to generate electricity (van der Linden 2006, Fowler 2007, EPRI-DOE 2007). CAES is seen as having high potential for use in both bridging power and energy management applications (Lemofouet & Rufer 2006, Lund & Salgi 2009).

Location on Grid

CAES storage systems are located in the generation feeder of a power system.

Deployment Status and Existing Installations

CAES technologies have been available for commercial applications for over 30 years. The first commercial CAES was a 290 MW unit, built in Hundorf, Germany in 1978. This was followed by a 110 MW unit built in McIntosh, Alabama, which was the first of its kind in the United States. Haddington Ventures is currently developing the largest CAES in the US. Upon completion, this will be a 2700 MW plant, slated for construction in Norton, Ohio (ESA 2009). There are several projects planned, utilizing different storage methods. These projects include: a 540 MW project in Matagorda County, Texas; and a 200 MW project under development in central Iowa (van der Linden 2006).

**Pumped Hydro**

Conventional pumped hydro energy storage uses two water reservoirs, separated vertically by height. During off-peak hours, water is pumped from the lower reservoir to the upper reservoir. When needed, the water flow is reversed to generate electricity. Underground pumped storage, using flooded mine shafts or other cavities, is technically possible. The open sea can also be used as the lower reservoir. Adjustable speed machines are now being used to improve efficiency. Pumped hydro is available at almost any scale, with discharge times ranging from several hours to a few days. They are 70% to 85% efficient. Pumped storage is the largest capacity form of a grid storage system now available (Lindley 2010).

There are over 90 GW of pumped storage in operation globally, which is about 3% of worldwide generation capacity. Pumped storage plants are usually characterized by long construction times and high capital expenditures. Pumped storage is the most widespread energy storage system in use on power networks for energy management (ESA 2009).

Location on Grid

Pumped hydro technology is located in the generation feeder of a power system.

Deployment Status and Existing Installations

Pumped hydro is the most commonly used energy storage system in the world. According to Industcards.com, pumped hydro plants in the US include the following:

- Bath County, VA - operated by Dominion Virginia Power. This is the largest pumped hydro power plant in the world; building cost: $1.7 billion. It has been in operation since 1985.
- Castaic, CA - operated by the Los Angeles Department of Water and Power. This plant has been in operation since 1973. It underwent a modernization process, which was completed in 2007.
- Ludington,MI - operated by CMS Energy, jointly owned with DTE.
- Muddy Run, PA - operated by Exelon Power. Upon completion in 1968, this was the largest pumped hydro station in the world. The primary connection consists of a 220kV circuit connection to the Peach Bottom nuclear plant in PA.
- Northfield Mountain, MA - operated by FirstLight Power Resources.
- Rocky Mountain, GA - operated by Oglethorpe Power Corporation. This plant has been in operation since 1995. It was the last major pumped storage plant built in the USA.

**Flywheels**

Flywheel energy storage systems are comprised of a rotating cylinder, made up of a shaft joined to a rim, supported on a stator by magnetically levitated bearings, which reduce friction and wear from bearings, thus increasing the life of the system. Some designs utilize hollow cylinders, allowing mass to concentrate on the outer radius of the battery (Ribiero et al 2001, ESA 2009). To maintain efficiency, the flywheel system is operated in a low vacuum environment, which reduces drag and friction, and is contained in a vessel. The flywheel is connected to a generator mounted onto the stator that, through some power electronics, communicates with the utility grid. Flywheels have been considered for several power quality applications; they can be used for peak shaving and enhancing grid stability (Ribiero et al 2001).

The main parts of a flywheel are the power convertor, controller, stator, bearings and a rotor.

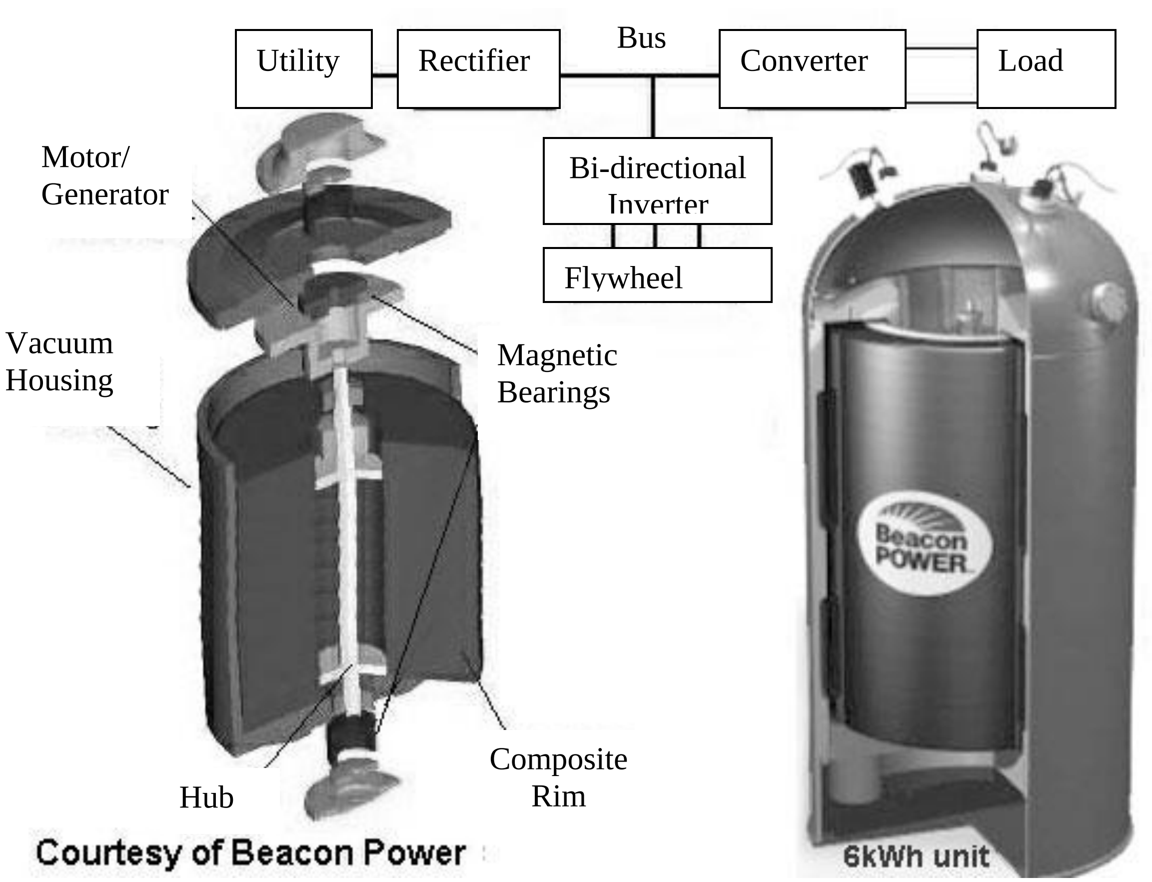



**Figure 4.3- Schematic diagram of Flywheel (Source Beacon Power 2010)**

Location on Grid

Flywheels can be located on both the generation and the distribution feeders of a power system.

Development / Deployment Status and Existing Installation

Flywheels were originally developed for aerospace, for uninterrupted power supply (UPS) applications. Beacon Energy reintroduced its 4th generation flywheel technology—the Flywheel Energy 25—for power generation and distribution frequency regulation. Companies like Active Power, Inc., AFS Trinity Power, Piller Gmb, and Urenco Power Technologies Limited are involved in flywheels (ESA 2009). Flywheels have been installed in small quantities as UPSs in data centers and hospitals (Lindley 2010).

Beacon Power is building a 20 MW Flywheel plant in Stephentown, NY, to be completed in 2011. It will be the first commercial frequency regulation plant in the world.

**Superconducting Magnetic Energy Storage (SMES)**

Superconducting magnetic energy storage (SMES) is made up of a large superconducting coil operating at cryogenic temperatures. The energy is stored in magnetic fields generated by the flow of DC through the superconducting coil. The SMES system is connected to an AC system, which is used to charge or discharge the coil through a conversion system. Two types of conversions are used: current source converter (CSC) and voltage source converter (CSC) (Ribeiro et al 2001,van der Linden 2006, Hasan et al 2010). The efficiency of SMES is its ability to quickly respond to power interruptions. This makes it attractive for several applications. SMES has been utilized for energy management load leveling; bridging power-contingency reserves or UPS; and power quality and reliability—dynamic stability, transient stability, voltage stability; and frequency regulation (Ribiero et al 2001, van der Linden 2006).


**Figure 4.4 – Superconducting Magnetic Energy Storage (Source sharp-world 2011)**

<u>Location on Grid</u>

SMES can be located on both the generation and distribution feeders of a power system.

<u>Development / Deployment Status and Existing Installations</u>

SMES batteries are commercially available. Wisconsin Public Utilities Corporation installed 6 D-SMESs made by American Superconductors, to handle power quality issues in its WPS Northern Loop system (van der Linden 2006)

## Battery Energy Storage Systems

According to the National Renewable Energy Laboratory (NERL), battery energy storage systems (BESS) include lead-acid, nickel metal hydride, lithium-ion, and lithium polymer and nickel cadmium batteries.

### A. Lead-Acid Battery

Lead-acid is one of the oldest, most developed and most used battery technologies. This battery is low cost and a storage choice for power quality and UPS. Its use for energy management has been very limited, however, due to its short cycle life. Lead-acid batteries cannot deliver a fixed amount of energy over long time periods. Nevertheless, lead-acid batteries have been used in a few commercial and large-scale energy management applications, the largest being the 40 MW system in Chino, California, built in 1988 for Southern California Edison(Bharat and Dishaw 1998, ESA 2009).

**Figure 4.5 – Lead Acid Battery (Source: ESA 2009)**

Location on Grid

Lead-acid batteries have been installed on distribution feeders, and as UPS backup systems for consumer-end applications in residential and commercial areas (Dishaw 1998).

Development / Deployment Status and Existing Installations

There is ongoing research for adapting lead-acid batteries for commercial grid applications. In 1998, Southern California Edison installed a 10MW lead-acid BESS at its substation in Chino, California (Dishaw 1998, ESA 2009).

**B. Lithium - Ion (LI-Ion) Battery**

Lithium-ion batteries have a cathode that is a lithiated metal oxide ($LiCoO_2$, $LiMO_2$, etc.); the anode is made of graphitic carbon in a layered structure. An electrolyte of dissolved organic carbon and lithium salts (e.g., $LiPF_6$) surrounds the anode and the cathode. When the battery is charged, the lithium atoms in the cathode become ions and migrate through the electrolyte toward the carbon anode, where they combine with external electrons and are deposited between carbon layers as lithium atoms. This process is reversed during discharge (ESA 2009).


**Figure 4.6 – Li-ion Battery (Source: NASA 2010)**

Location on Grid

Lithium-ion batteries are presently being used on distribution feeders, for power quality applications, and have been adopted as UPS for industrial and commercial applications.

Deployment Status Existing Installations

Li-ion batteries are expected to control over 50% of the small portable appliance battery market in a few years. There are, however, some challenges to making large-scale Li-ion batteries for commercial applications. The production costs and the need for special packaging needs are problems that several companies are still working on (ESA 2009).

AEP is installing 80 lithium-ion batteries, as community energy storage systems, in the northeastern part of Columbus, Ohio; this is to be completed in 2011(Atkins 2010)

**Flow Batteries**

Flow batteries are fuel cells that, by means of a reversible electrochemical reaction between two electrolytes, store and release energy continuously at a high rate. The main flow batteries are Vanadium Bromide (VRB), Zinc Bromide (ZnBr), and Sodium Bromide (NaBr) batteries. All these batteries work on the same principle—the bigger the tank, the more energy that can be stored (van der Linden 2006).

**A. Vanadium Redox Battery (VRB)**

The Vanadium Redox Battery (VRB) is a flow battery that uses liquid vanadium-based electrolytes, stored in external tanks filled with electrolytes that flow into a regenerative power cell, producing electric power electrochemically. A key advantage of the VRB is that, by simply increasing the size of the electrolyte tanks, more energy can be stored (Fabjan et al. 2001). The power rating is a function of the regenerative fuel cell and its inverter. Flow batteries have a very low rate of internal discharge and parasitic losses. The VRB has an estimated lifespan of more than 10,000 cycles. An issue with the VRB is its relatively low volumetric energy density, thus it requires a sizeable footprint. Improvements in the battery's membrane and electrolyte technologies are needed to reduce VRB capital costs (ESA 2009, Fabjan et al 2001).

Some of the advantages of VRB over other storage systems are:

- Long life with few disposal issues
- High efficiency
- Speed of response to waveform deviations
- Rapid charge and discharge
- Expandability

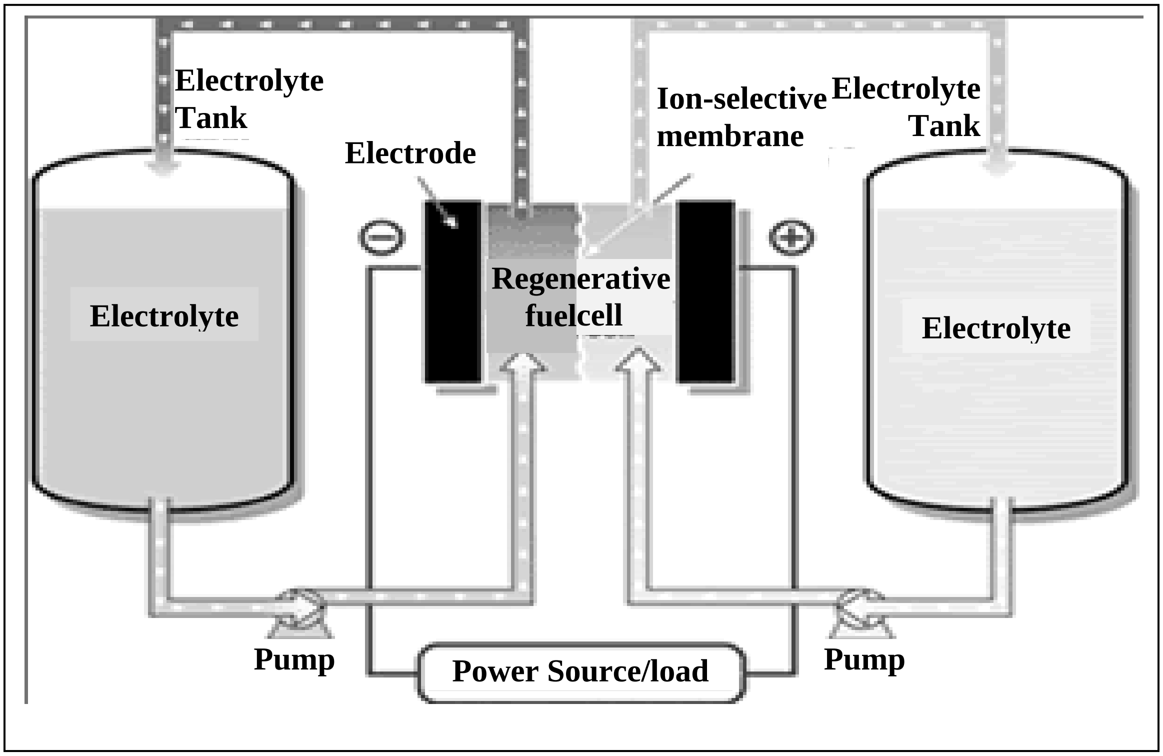



**Figure 4.7. Vanadium Redox Battery Flow Schematic (Sources NETL 2009)**

Location on Grid

The VRB is located at the generation and distribution feeders.

Deployment Status and Existing Installations

PacifiCorp installed a VRB Energy Storage System in Castle Valley, Utah in 2003(VRB 2007).

**B. Zinc Bromide (ZnBr) Battery**

This battery utilizes a circulation system to continuously feed reactants from external reservoirs into the battery stacks. It is, therefore, classified as a "flowing electrolyte," or flow battery. The stack contains a series of bipolar electrodes and porous separators between two monopolar (one negative and one positive) terminal electrodes.

The bipolar electrodes allow the negative (zinc) reaction and the positive (bromine) reaction to occur on opposite sides of the same electrode (Norris et al 2002).

**Figure 4.8. Zinc Bromide Battery (Source: Greentech 2010)**

Location on Grid

The ZnBr battery is installed on the Distribution feeder for Energy Applications.

Development / Deployment Status and Existing Installations

Exxon developed the ZnBr battery in the 1970s. ZBB Energy Corporation, in collaboration with the Department of Energy (DOE) and The California Energy Commission (CEC), undertook a demonstration in 2006. Preliminary testing was conducted at the Distributed Utility Integration Test Facility in San Ramon, CA. This testing confirmed the ability of ZnBr storage systems to work in series and parallel 50 kW battery modules, and to remotely charge or discharge a mobile system with approximately 500 kW of capacity from the battery system (CEC & DOE, 2006). According to ZBB Energy Corporation, energy storage systems have been installed for the following:

- Envinity (State College, Pennsylvania)
- Oregon State University (Corvallis, Oregon)
- Pacific Gas and Electric Company (San Francisco, USA)
- Detroit Edison (Detroit, USA)
- Sandia National Laboratories (Albuquerque, USA)

### C. Metallic-air Batteries

Metallic-air batteries have been in utilized in fuel cells, with the use of Zinc metal, for several years. To increase capacity, however, high density metals like Lithium, Magnesium, and Aluminum are being explored for usage as the anode of the battery (Armand & Trasacon 2008, ESA 2009). The cathodes or air electrodes are often made of a porous carbon structure, or a metal mesh covered with catalysts. The electrolytes are often manufactured of a good hydroxide (OH) ion conductor, such as Potassium Hydrochloride. Metal-air batteries are compact and have the potential to be the least expensive storage system. They have been deemed to be mostly environmentally safe. However, charging and recharging the battery is deemed to be inefficient and expensive (ESA 2009).

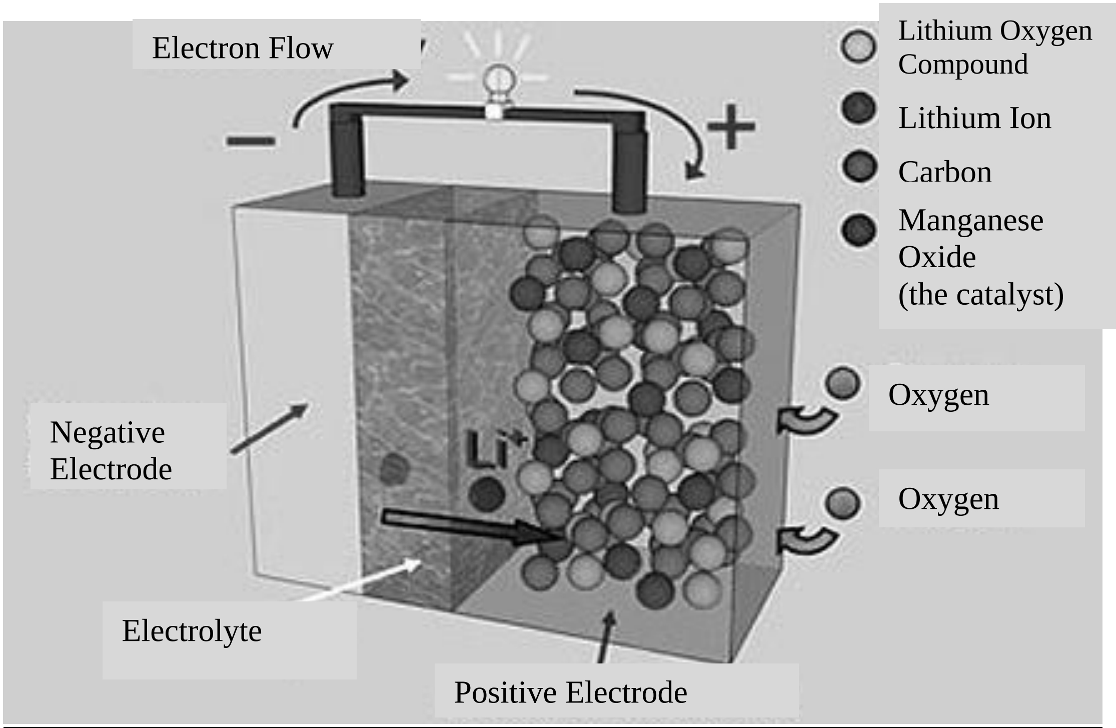



**Figure 4.9. Metallic Air Battery (Source: General Motors 2010)**

Location on Grid/Grid Application

The metallic air battery is located on the distribution feeder for energy application

Deployment Status and Existing Installations

Metallic-air batteries have the potential of being cheaper lightweight energy storage due to their potentially high energy densities (Abraham 2008). The first metal-ion battery was demonstrated in the early nineteen-nineties. Several ongoing research projects are looking at adopting Metal-Air Batteries for commercial grid applications at MIT and other institutions. There are no existing commercial installations for metallic-air batteries**.**

**Community Energy Storage**

This small distributed energy storage system is connected to secondary transformers that serve a group of homes. Individual batteries can be used to provide backup power to service individual homes or can be aggregated to work together as a virtual backup storage system for the grid. CES is utilized for power quality deficiencies and for the efficient integration of renewable resources (AEP 2009, Nourai 2010). In the future, CES can be controlled through an integrated communications system, to be used for demand response, in conjunction with PHEV on another part of the grid, as backup power in times of emergency (AEP 2009).


**Figure 4.10. Community Energy Storage (Source: AEP 2009)**

<u>Location on Grid</u>

Community energy storage is installed on the distribution feeder for energy smoothing and UPS applications.

Deployment Status and Existing Installations

Several utilities, like AEP and DTE, are deploying CES in limited quantities and in demonstration. Several battery manufacturers are rolling out batteries of varying capacities for use as CES. AEP is installing 80 lithium-ion batteries in northeastern parts of Columbus, Ohio, to be completed in 2011(Atkins 201

**Table 4.1 - Comparison of Storage Systems (Adopted from ESA 2009)**

| Energy Storage Device | Advantages (relative) | Disadvantages (relative) | Power Application* | Energy Application* | Remarks |
|---|---|---|---|---|---|
| Pumped Storage | High Capacity, Low Cost | Special Site Requirements | □ | ■ | |
| CAES | High Capacity, Low Cost | Special Site Requirements, Need Gas Fuel | □ | ■ | |
| Flow Batteries: VRB ZnBr, PSB | High Capacity, Independent Power and Energy Ratings | Low Energy Density | ● | ■ | |
| Metal-Air | Very High Energy Densities, | Electric Charging is Difficult | ■ | ■ | |
| NaS | High Power & Energy Densities, High Efficiency | Production Cost | ■ | ■ | Large Capacity obtained by connecting batteries |
| Li-ion | High Power & Energy, High Efficiency | High Production Cost, Requires Special Charging Circuit | ■ | □ | Adoption for CES |
| Lead-Acid | Low Capital Cost | Limited Cycle Life when Deeply Discharged | ■ | □ | |
| Flywheels | High Power | Low Energy Density, High Production Cost | ■ | □ | |

* Not Feasible or Economical □ Reasonable for Application ● Fully Capable and Reasonable ■

### 4.3.2 Advanced Superconducting Transmission Cables

Several advancements in cable technology have improved the ability to transport electricity in high currents. Advance superconducting transmission cables can carry about 1.5-8 times the current capacities carried by steel core cables. Superconducting cables will transport currents between 500kv-800kv, for both AC and DC applications. These superconducting cables can transfer power with a 40% increase in efficiency, by decreasing sag through reduced heating (Malozemoff et al 2008, Ulliman 2009).

<u>Location on Grid</u>

Transmission cables are located on the transmission section of the grid. The most common advanced cables are (EPRI 2000, Ulliman 2009, and NETL 2009):

**High Temperature Superconducting (HTS) Cables**

This cable utilizes the ability of some conductors to have zero electric resistivity when they are cooled below their critical temperature. HTS cables are cooled by liquid nitrogen to their critical temperatures and are used to transport electricity. HTS cables will allow existing substations to service increasing power requirements and reduce the need for voltage transformation steps (EPRI 2000, McConnell 2005). HTS cables are primarily suitable for direct current applications; it is especially advantageous for underground installations, due to small trench requirements and less need for right-of-way paths. As such, it is more economical for use in large population areas, to carry high capacity power (McConnell 2005).

HTS are divided into first and second generation HTS cables, depending on their construction properties (NETL 2009).

HTS cables have several advantages over traditional copper cables. The advantages of HTS cables are (ORNL 2005, McConnell 2005, and Hirose et al. 2006):

- Generates essentially no waste heat or electrical losses
- Use of environmentally benign liquid nitrogen for cooling
- Can be installed into existing conduit infrastructure
- Takes up less space than conventional cables, leaving room for future expansion

**A. First Generation HTS Cables (1G HTS)**

First Generation HTS Cables (1G HTS) can be used to transmit high currents and large power quantities, with little loss from heating in the conductor at lower voltages. This low loss from heating allows the use of small trenches for underground applications (ORNL 2005, NETL 2009),

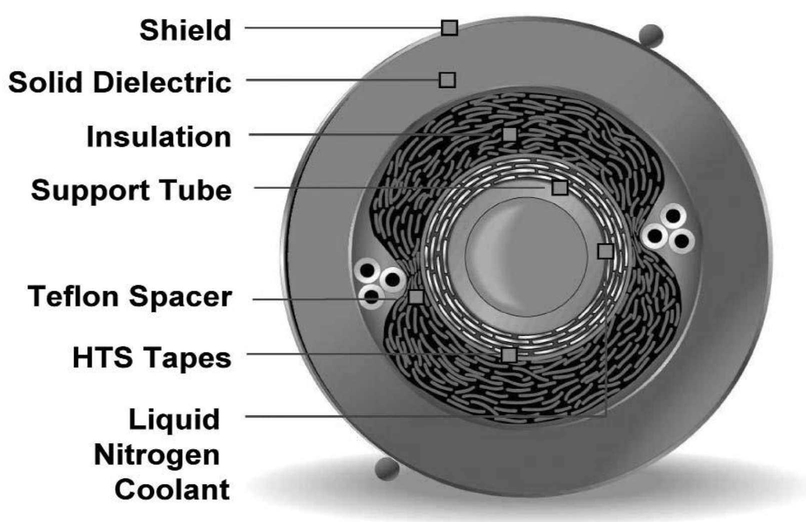



**Figure 4.11. Cross section of typical HTS cable (Source: EPRI 2000)**

Deployment Status and Existing Installations

The 1G HTS cable is still in development; it is available in limited commercial quantities. Due to its high cost, there is a manufacturing limitation. It is expected to be widely available in about 1 year (NETL 2007c, NETL 2009).

SuperPower, Inc.—in partnership with Linde, Sumitomo Electric Industries, Ltd. from Japan and National Grid—have designed, manufactured, and installed an underground, high-temperature superconducting (HTS) power cable between two National Grid substations in Albany, NY.

**Figure 4.12 – HTS Underground Cables Connected to Transformer Substation (Source: AMSC 2010)**

**B. Second Generation HTS Cables (2G HTS)**

Over the past few years there have been rapid gains in the development of second generation HTS (2G HTS) cables. A 2G HTS cable is achieved by the annealing of a conductor with a high resistivity stabilizer, like Yttrium barium copper oxide (YBCO). The wires are then laminated with copper, stainless steel, or brass metals, to provide fortification, durability and certain electrical characteristics needed for several electrical applications like power transmission. 2G HTS cables have the ability to carry 10 times greater current than the regular copper cable of a similar cross section area (Malozemoff et al 2008).

Deployment Status and Existing Installations

American Superconductor Corporation introduced their 2G HTS cables in a pre-pilot version of the cables in 2005. 2G HTS is now available in limited quantities; it is expected to be commercially available in the next few years ((Malozemoff et al 2008, EPRI 2009, NETL 2009). There are no existing commercial installations of 2G HTS.

**Aluminum Conductor Composite Core (ACCC®)**

ACCC's strength as a conductor is achieved through a hybrid carbon and glass fiber core, which is wrapped with trapezoidal-shaped aluminum strands. The high strength structural core carries the electrical load, and the trapezoidal aluminum strands carry the electrical current. The composite core of the ACCC conductor is much lighter and about 40% stronger than conventional copper cable or high-strength steel core cable. Its lighter weight allows the use of fewer transmission towers in carrying the equivalent amount of load used by conventional conductors, and can incorporate about 25% to 30% more aluminum (conductive material), without any additional weight. The fiberglass core in the ACCC conductor prevents corrosion from galvanization. The conductor heats less and, therefore, sags at a higher temperature than conventional cables. (Jones 2006, Kopsidas & Rowland 2009, Ulliman 2009).

**Figure 4.13 – Aluminum Conductor Composite Core. (Source: CTC 2010)**

Deployment Status and Existing Installations

Composite Technology Corporation (CTC) introduced the ACCC cable in a limited commercial application in 2006. The ACCC cable is now available commercially (Jones 2006). In 2006, Utah Power used CTC's ACCC conductor to re-cable a 10-mile transmission line. Since then, there have been several installations throughout the United States and worldwide (Jones 2006, CTC 2009).

**Annealed Aluminum Steel Support with Trapezoidal Wire (ACSS/TW)**

Annealed aluminum steel support with trapezoidal wire (AASS/TW) is made of trapezoidal wires wrapped around a steel core. Replacing the round wires with trapezoidal-shaped wires created a more compact conductor, with the same metal area as a traditional conductor, but less susceptible to ice and wind loading, due to its reduced diameter (Thrash 1999). The annealed aluminum wire construction enables it to continuously operate up to temperatures of 250 degrees with little sag, even though it carries 32% more current (Ahmad et al 2005,NETL 2009).

Deployment Status and Existing Installations

The ACSS/TW conductor is commercially available; several companies market it under different brand names. CenterPoint Energy was the first to install ACSS cables on an 80 mile, 345kV transmission project in 2007(Harms 2007).

### Aluminum Conductor Composite Reinforced (ACCR)

Aluminum Conductor Composite Reinforced (ACCR) relies on a composite core of purified aluminum strands and ceramic fiber, surrounded by an outer strand made of temperature-resistant aluminum zirconium cables (3M 2003). This build-up enables the conductor to operate at temperatures of up to 240 degrees (3M 2003, NETL 2009).

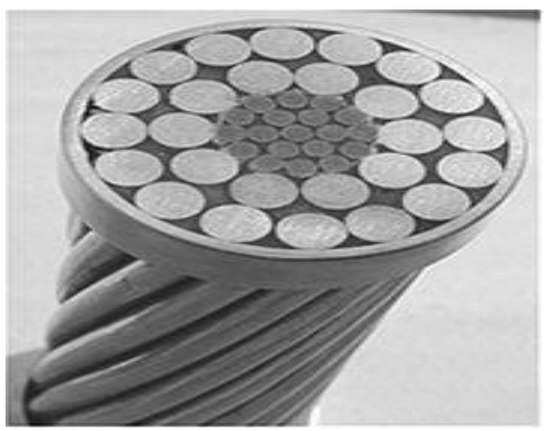


**Figure 4.14 Aluminum Conductor Composite Reinforced (Source: Solarsofa.com 2010)**

Deployment Status and Existing Installations

ACCR is commercially available and has been installed on several projects worldwide since 2001 (NETL 2007c). Hawaiian Electric installed a 477-kcmil Composite Conductor on the North shore of the island of Oahu, Hawaii, to make use of the conductor’s corrosion-prevention properties against the oceanic conditions of the area (3M 2003).

### 4.3.3 Grid-Tied Inverter (GTI)

A grid-tied inverter (GTI) is a special inverter used to integrate renewable energy sources, like solar farms, with the AC grid. GTI is used to mitigate the intermittent characteristics of renewable energy sources while it performs its primary function of converting DC to AC (Ton and Bower 2005). There are two types of inverter systems: those that connect PV cells directly to the grid, and those that connect PV cells to storage devices, which are connected to the grid.

**Figure 4.15– Grid-Tied Inverters (Source: wsetech.com 2010)**

<u>Location on Grid</u>

A GTI is installed on the renewable generation connection to grid

<u>Deployment Status and Existing Installations</u>

GTI are commercially available and have been installed on several commercial and residential renewable-energy-generation installations.

### 4.3.4 Smart Meters

The smart meter is an intelligent meter installed at residential premises and commercial buildings. The meter is deemed to be "smart" because it is able to perform three main functions (Houseman 2005, van Gerwen et al 2006):

- The ability to measure the electricity used (or generated)
- The ability for the utility company to remotely switch the customer off
- The ability to remotely control the maximum electricity consumption

The electric smart meter uses an internally installed modem to exchange communications between the utility company and the customer. Data—e.g., the quality of the power at the load source, the amount of power being used, the equipment in use, electricity prices, and more—can be accessed through the use of Bluetooth technology, Zigbee, Global Positioning System (GPS) or an existing internet connection between the smart meter and existing home appliances or a home display (van Gerwen, et al 2006). Smart meters are classified as both an advanced component, and a sensing and measurement technology. More details of smart meters were presented as part of the discussion of automated metering infrastructure (AMI) in section 4.4.8.

### 4.3.5 Demand Response Load Control Receiver

Demand response refers to mechanisms used to encourage consumers to reduce demand, thereby reducing the demand for electricity. Since electrical generation and transmission systems are generally sized to correspond to peak demand; lowering demand reduces overall operation costs for utility and generation companies. There are two types of demand response, based on the purpose: emergency demand response and economic demand response. Emergency demand response is primarily needed to avoid outages, while economic demand response is used to help utilities manage daily system peaks (Schellenberg 2008).

The load control receiver is an outdoor-installed computer that measures power usage and controls peak demand by shedding load. Some loads, e.g. A/C, dryers, and water heaters, are not permitted to run simultaneously, as that causes high demand charges. The load controller allows the utility company to shed loads in periods of peak demand.


**Figure 4.16 - Load Control Receiver (HAI 2010)**

<u>Location on Grid</u>

The load control receiver is located on the home area network (HAN).

<u>Deployment Status and Existing Installations</u>

Load control receivers have been available since the 1980s. Some utilities have utilized them for load shedding during peak demand periods. Several utility companies, including Detroit Edison in Michigan, have installed load control receivers in their areas of operations.

### 4.3.6 Plug-In Hybrid Electric Vehicles (PHEV) & Vehicle-to-Grid (V2G) Technology

Plug-In Hybrid Electric Vehicles (PHEVs) are electric-run vehicles with larger batteries than hybrid gas electric vehicles, and have the capacity to drive 30-50 miles, exclusively using electric power, switching to gasoline for longer trips. (Lazar et al 2008). There is ongoing research for adopting the 60 Hz electricity stored in the batteries of PHEV as mini energy-storage devices, and deploying this power to respond to demand hikes on the grid, as well as in utilizing large fleets of PHEV as sources of emergency power (Denholm and Short 2006).


**Figure 4.17 – Plug In Hybrid Electric Vehicle (Source: Blog.niot.net 2010)**

<u>Location on Grid</u>

The PHEV is located on the Home area network (HAN) in either a residence or a commercial charging station.

<u>Deployment Status and Existing Installations</u>

PHEV are now commercially available, several car companies are producing their version of PHEV. However, utilizing PHEV batteries as backup energy storage systems is in research.

### 4.3.7 Plug- In Electric Vehicles (PEV) Charging Station

These are commercial station where plug-in hybrid vehicles (PHEV) vehicles can be charged. The charging stations usually meet a level 2 or 3 charging designation. Level 2 charging stations which is the most common type of charging station employs 240 V AC and 40A current. The level 3 chargers will be fast charging employs a 480VAC current a level three charger should be able to achieve 50% charge in 10-15 minutes (DOE 2008).

**Figure 4.18. PHEV Charging Station**

<u>Location on Grid</u>

THE PHEV charging stations are located in the home area network either in a residential setting or in commercial parking lots or commercial charging stations.

<u>Deployment Status and Existing Installations</u>

Level 2 PHEV chargers are commercially available; level 3 PHEV chargers however are available in limited quantities commercially. Companies have started

installing commercial charging stations in several states around the country. 4.7 million charge stations are expected to be installed by 2015 (Addison 2010).

### 4.3.8. Other Technologies

There are a number of other advanced component technologies. Some of these technologies are summarized in table 4.2.

**Table 4.2 Sample Advanced Component Technologies (Adopted from NETL 2009)**

| **ADVANCED COMPONENTS** | | | |
|---|---|---|---|
| Technology | Deployment Status | Description | References |
| Current Limiting Conductor (CLiC) | 2 years | CLiC are modules that are attached to a line or transmission tower. When CLiC senses an overload in the conductor, it uses magnetic induction to transfer loads to more receptive parts of the line, to prevent thermal overload on the line. Georgia Institute of Technology School of Electrical Engineering, in collaboration with DOE and several companies are developing CLiC. | http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1668661&userType=&tag=1 www.oe.energy.gov/DocumentsandMedia/Intelligent_Power_Infrastructure_Consortium_Divan.pdf |
| D-VAR or DSTATCOM | Commercially available | D-VARS can be sited on the Transmission and Distribution interfaces to provide voltage support. D-VARS reduce voltage variations through the use of transistors. | www.sgiclearinghouse.org/Technologies?q=node/2176 |
| Advanced Online Tap Changer (OLTC) for Transformer | 1-2 | OLTC is used to change the tapping connection of the transformer, winding, to change the voltage ratio while the transformer is still in service, without interrupting the load. | Douglas. M. Getson. On-load Tap Changers. Document updated: 2002-11-06. http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1047553 |
| Static VAr compensator (SVC) | Commercially Available | SVC provides fast-acting reactive power on high voltage transmission networks (De Kock and Staruss 2004). | |

## 4.4. SENSING AND MEASUREMENT

Sensing and measurement technologies receive and convert information from components into data. These technologies check the operation quality of the individual components and the grid as a whole. The smart meter and the home area network (HAN), which are expected to enable demand response (DR), are the most widely anticipated changes for the customer end of the grid. At the utility and transmission levels, several wide-area monitoring systems, like line sag meters, are being employed at the transmission and distribution ends of the grid. These advanced sensing measurement tools will track and transmit data to power system operators (NETL 2007b). There are several technologies available now on the market, but adaptation has been hindered by acceptance.

This section discusses the following sensing and measurement technologies:

- RF temperature and Current Sensor for Conductors
- Line Tracker Community Meter
- Line Sag Monitors
- Phasor Measurement Units
- Wide Area Monitoring Systems (WAMS)
- Substation Automation Sensors
- Advanced Metering Infrastructure (AMI)
- Smart Meters
- Home Area Networks (HAN)
- Home/Consumer Gateway

- Miscellaneous Technologies

### 4.4.1. RF Temperature and Current Sensor for Conductors

This sensor records the transmission temperatures and current magnitudes on the overhead transmission or distribution conducting cables, and transmits the data to control stations wirelessly (EPRI 2009).

**Figure 4.19 – RF Temperature and Current Sensor (Source: EPRI 2009)**

<u>Deployment Status and Existing Installations</u>

This sensor is being developed by the Electric Power Research Institute (EPRI) and is under demonstration.

### 4.4.2. Line Tracker Communicating Meter

The line tracker communications device is used to record fault currents and load profiles. This will help in quick responses to outage detection and restoration.

**Figure 4.20. Line Tracker (Source: GridSense 2010)**

<u>Deployment Status and Existing Installations</u>

The Line Tracker is being developed by EPRI. This technology is available in limited quantities.

### 4.4.3. Line Sag Monitors (Sagometer)

This is a device installed on the transmission tower to monitor cable sag on overhead transmission cables in real time, and to communicate the results via a communication station. The Sagometer was developed by EPRI and has been commercialized by EDM (EPRI 2009).

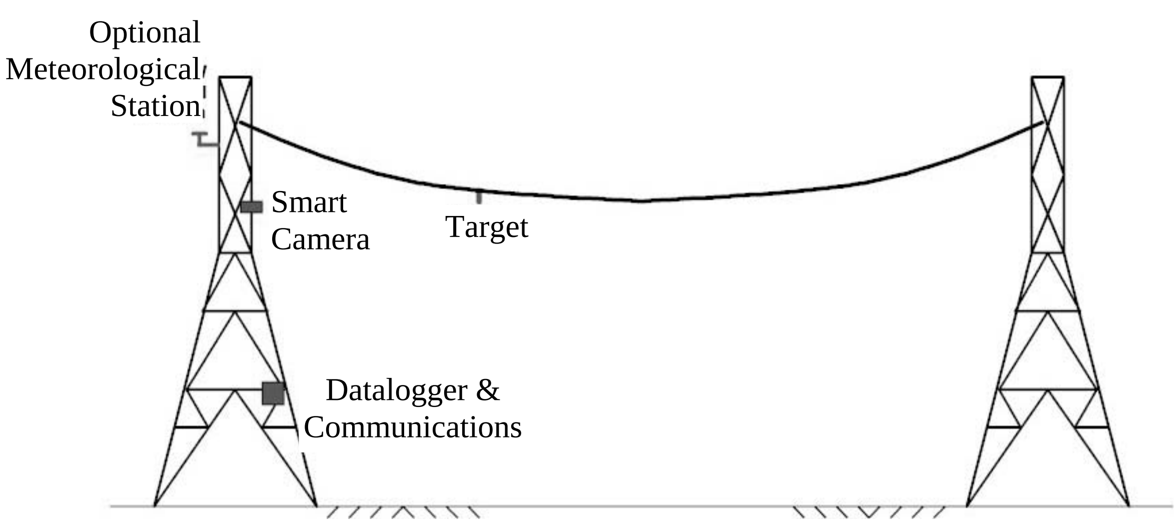



**Figure 4.21 – Schematic Layout of Sagometer Setup (Source: EDM 2010)**

The Sagometer is mounted on one of the supporting structures of the span to be monitored. The smart camera is aimed down the span, on a target attached to one of the conductors. The smart camera measures the sag clearance; this information is then communicated in real time to the control monitoring station, through wireless or radio frequencies (EDM 2008).

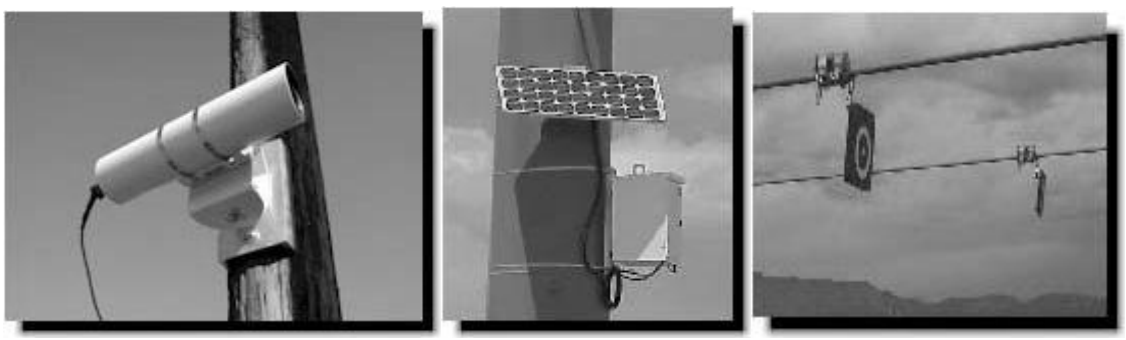


**Figure 4.22– Sagometer (Source: EDM 2010)**

Development / Deployment Status and Existing Installations

Sag meter monitors developed by EPRI are under demonstration, in limited commercial quantities, through EDM International in Colorado.

### 4.4.4. Phasor Measurement Units

These are high-speed sensors that are used to monitor power quality and to automatically respond to changes in voltage quality in real time. This technology can detect and represent the instantaneous capacity factor and the phase angle of the current. Once this data is known, it can be precisely monitored and disseminated to control centers for action. The harmonious and efficient integration, via PMU, is a prerequisite for feeding renewable and decentralized energy generation, e.g. from wind turbines of varying sizes, into large networks, thus ensuring an efficient and, above all, reliable supply of renewable energies (Energynautics 2009).


**Figure 4.23. - Phasor measurement unit (Source: EPL 2010a)**

<u>Location on Grid</u>

The PMU is can be located on both the generation and distribution Substations

<u>Deployment Status and Existing Installations</u>

PMU are commercially available. They have been installed in several substations as part of the utilities companies' distribution management systems (DMS).

### 4.4.5. Wide Area Monitoring System (WAMS)

Wide Area Monitoring Systems (WAMS) continuously monitor power by utilizing synchronized phasor measurements that can stream data in real time. The WAMS help in fault detection and isolation. Though several utilities in the US have deployed PMU networks widely, impediments still exist, such as cost and reliability in implementing WAMS systems (NETL 2009). WAMS utilize GPS technology to give every phasor measurement a time and location stamp for easy fault location and tracking.

Most of the existing WAMS utilize several existing communication protocols. WAMS will be most effective when the monitoring capacity of the system is no longer limited to the area of operation, but covers the whole grid (Hadley et al. 2007).

Location on Grid

WAMS are installed on transmission feeders.

Deployment Status and Existing Installations

Commercially available in limited quantities in the western United States.

### 4.4.6. Substation Automation (SA) Sensors

To fully realize the advantages of smart electric grids, transmission and distribution substations will have to be fully automated and able to relay information between generation and distribution sources, and between distribution sources and the end-users of electric power. A substation can be made 'smart' through the installation of intelligent electronic devices (IEDs) in its basic components, to enable both quick detection and correction of faults in the grid, and communication among the various components of the power grid.

For a substation to be considered smart, the following main components will have to be upgraded with IEDs:

- Transformers
- Circuits Breakers
- Relaying and Protection Equipment
- Optical Measuring Systems
- Station Batteries

- Superconductors
- Substation Information Technology, and Supervisory Control and Data Acquisition (SCADA)

**Substation-Wide Antenna Arrays**

This technology continuously monitors and accurately locates partial discharges of the substations' failing components through a fixed antenna array (EPRI 2009).

**Figure 4.24 - Antenna Array (Source: EPRI 2009)**

Development / Deployment Status and Existing Installations

This sensor is under demonstration.

**Transformers**

The transformer, which serves as the hub for collection and distribution of electrical energy, will have to be made "smart" by installing sensors to collect and communicate data on the power network. The basic working mechanics of the transformers have not changed much. The additional capabilities will be in analyzing voltage and current flow. This will, in turn, enhance the efficiency of the grid (Pacific Crest 2009)

Location on Grid

Smart transformers are installed in generation and distribution substations

**Transformer Tanks**

EPRI is conducting research on the development of a transformer tank and continuous oil filtration system with the ability to maintain transformer oil in “as-new” condition over a long period of time. This will prevent the broken down chemicals in the oil from affecting the transformer, thereby maintaining the integrity of the complete dielectric system in the transformer (EPRI 2001).

Development / Deployment Status and Existing Installations

A sensor developed by EPRI is under demonstration.

**Transformer-Metal Insulated Semiconducting (MIS) Gas in Oil Sensor**

The MIS sensor is a low-cost hydrogen sensor on a chip. There was a recent breakthrough in its development and in field demonstrations in transformers. This chip, which will be installed in the transformer, will detect hydrogen emissions in the tank and relay these measurements. These will then be sent wirelessly to the control centers of the utility or generation companies. The hydrogen determines the emission level, which can be monitored to determine the probability of repair needs in a transformer (EPRI 2009).

**Figure 4.25. Transformer-Metal Insulated Semiconducting (MIS) Gas in Oil Sensor (Source: EPRI 2009)**

Deployment Status and Existing Installations

This sensor, developed by EPRI, is under demonstration.

**Transformer-On-Line Frequency Response Analysis (FRA)**

The FRA was developed to measure the response of a transformer to faults in the systems, which are normal occurrences in grid operations (e.g. switching or lighting). The internal geometry of a transformer or other components of a substation (circuit breakers, insulators, disconnect switches, control equipment) can be identified by changes in the frequency response (EPRI 2003, EPRI 2009).

Development / Deployment Status and Existing Installations

This sensor is currently in demonstration.

**Fault Current Limiting High Temperature Super Conducting Transformers**

Fault current limiting high temperature superconductor (HTS) transformers employ the use of HTS conductors as coils, with liquid nitrogen to cool and insulate the coils in the transformer. These features make the transformer more efficient by reducing grid losses by about 40%, compared to traditional transformers (Schwenterly & Peva 2010). An HTS transformer has the advantage of being lighter in weight, has smaller units, lower lifecycle costs, and fewer hazards due to fire than traditional transformers (Chen & Jin 2008).

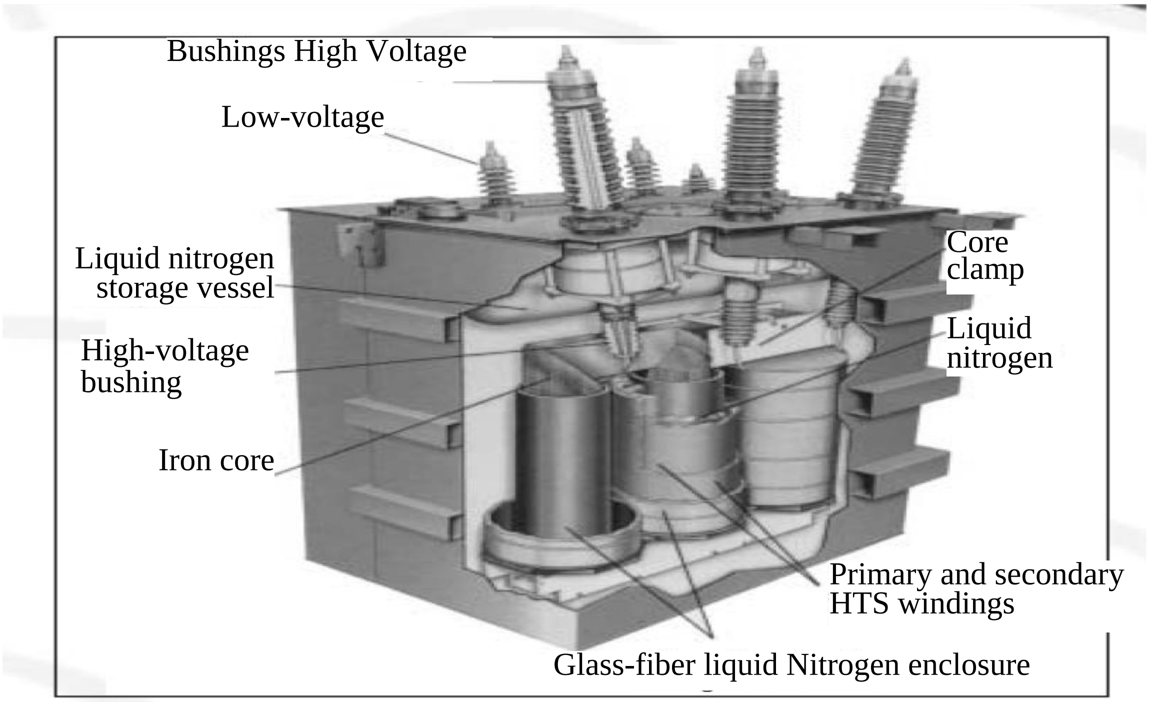



**Figure 4.26. Cut away View of an HTS Transformer (Source: DOE 2010)**

Location on Grid

HTS transformers will be installed in generation and distribution substations

Deployment Status and Existing Installations

The HTS transformer is being developed in joint-research collaboration between the DOE, Southern California Edison, Superpower Inc, Waukesha, and the Oak Ridge National Laboratories. The technology is in pre-commercial testing.

**Transformer 3-D Acoustic Emissions Technique**

This enables the detection and location of gassing sources in power transformers, through monitoring the partial discharges in the transformer (EPRI 2009, Nagamani et al 2005)

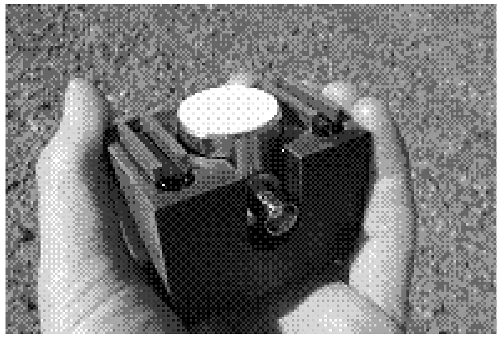


**Figure 4.27. 3D Acoustic Monitor (Source: EPRI 2009)**

Location on Grid

Transformer 3-D acoustic monitor is installed in the power transformers on the generation and distribution substations

Deployment Status and Existing Installations

Technology under demonstration by EPRI, and is being tested in limited commercial quantities with some companies.

According to EPRI, the following additional technologies are being researched (2009):

- Cost-effective high temperature insulating fluid
- Superconducting windings
- A non-mechanically driven load taps changer
- A transformer life assessment model
- Development of a prototype transformer with superconducting windings

## Circuit Breakers

### *Radio Frequency (RF) SF6 Density Sensors*

Sulfur Hexafluoride (SF6) is a gaseous dial electric gas used for insulation in circuit breakers. The sensor measures the density of the SF6 gas and transmits the results wirelessly (EPRI 2009).

<u>Deployment Status and Existing Installations</u>

This sensor, developed by EPRI, is under demonstration.

## Optical Measuring Systems

### *Substation-Wide Online Infrared*

This system uses ultrasound sensing with visual and infrared video, for continuous online monitoring of the substation by the installation of infrared thermographic cameras. The online monitor alerts the utility or generation companies to detected deviations in substation heating over the network (EPRI 2009).

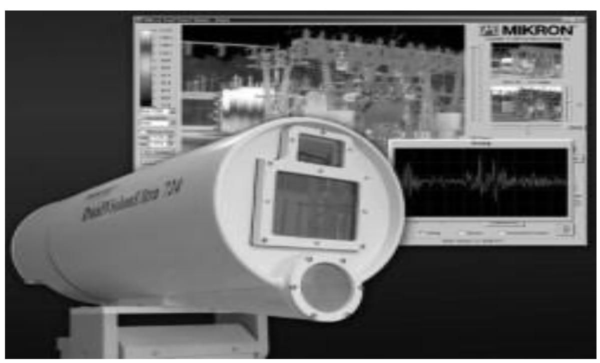



Figure 4.28 – Mikron Infrared Substation Camera (Source: EPL 2010b)

<u>Deployment Status and Existing Installations</u>

This sensor is under demonstration.

### 4.4.7. Advanced Metering Infrastructure (AMI)

According to Valigi & Di Matteo (2009) "Advanced Metering Infrastructure (AMI) refers to a system that measures, collects and analyzes energy usage, from advanced devices such as electric smart meters, through various communication media, on request or the basis of pre-defined schedule." AMI utilizes two-way communications to achieve these functions (EPRI 2007, Hart 2008).

AMI is an integration of several technologies. It consists of four main components: a meter at the customers' location; a communications network between the utility company and the smart meter the home area network; and the data management software at the utility, to track and control the communication and electric flow, as well as to serve as an interconnection to automated utility billing between the utility company and the consumer (EPRI 2007, Hart 2008). More technologies can be built into the systems, like GIS and data management applications.

AMI enables the utility company to undertake demand-response remotely at the customer level, and gives the consumer the ability to make informed decisions (NETL 2008). The home area network gateway reads and ties the meter into various end-use devices, and communicates with the service provider.

AMI is often confused with automated meter reading (AMR). AMI entails more than just the automated reading of meters. Table 3.3 shows the differences between AMI and AMR.

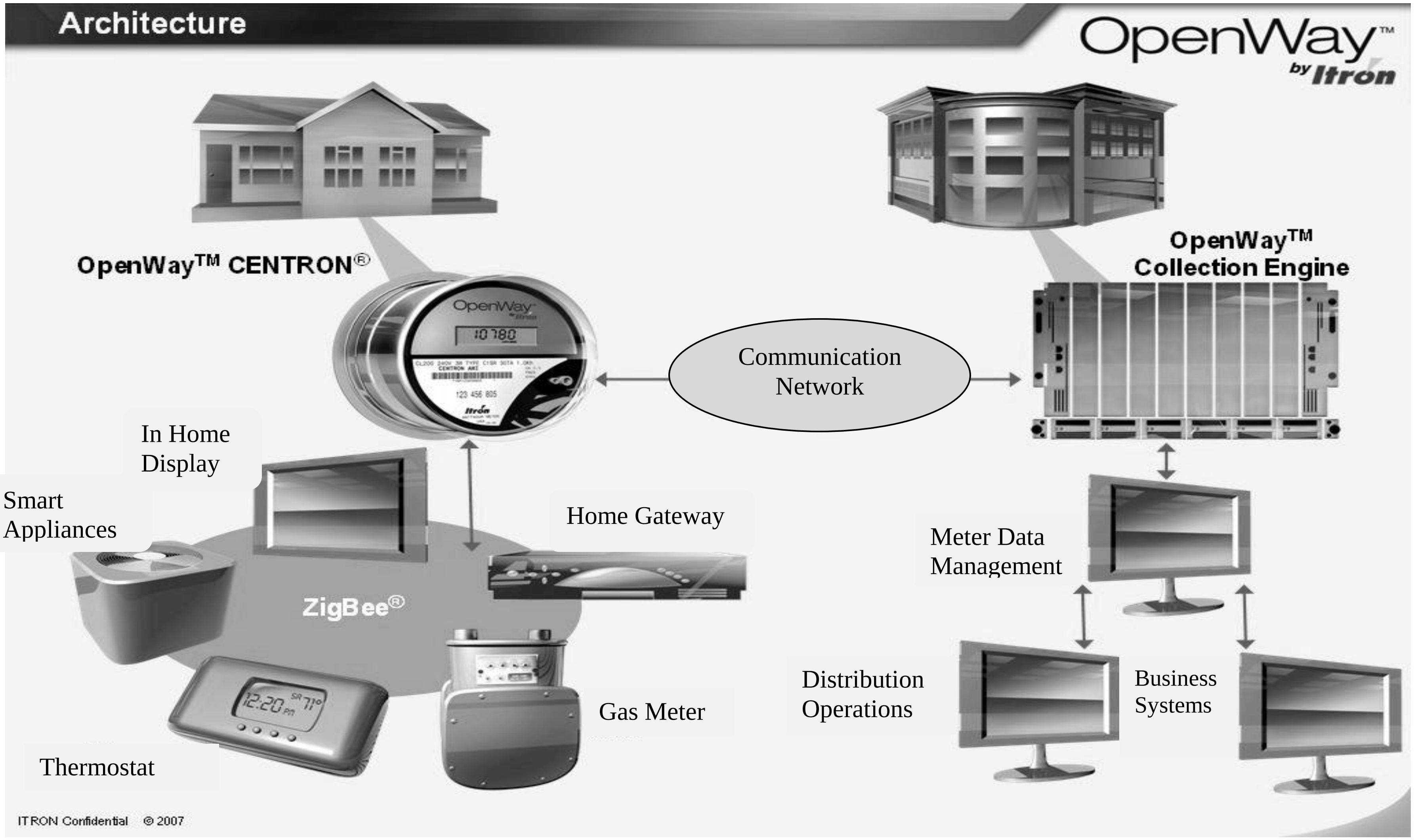



**Figure 4.29 - AMI Data and Software Relationships (Source: Ember 2010**

AMI, through the communications network, has the ability to transport control signals and prices to the smart meter, and to collect data from the home through the smart meter and send it to the utility company (Hornby et al 2008).

The most common AMI Communication Protocols used are (Bennett 2008):

- Radio Frequencies
- Z-Wave with 802.15
- ZigBee with 802.15
- WiFi with 802.11
- Bluetooth SIG with 802.11
- Low Power Wireless Area Network 6loWPAN with 802.15
- LonWorks

Deployment Status and Existing Installations

AMI deployment is ongoing among several US utility companies.

### 4.4.8. Smart Meters

The smart meter is an intelligent meter installed at residential premises and commercial buildings. According to van Gerwen et al (2006), the meter is deemed to be "smart" because it is able to perform three main functions: tracking the electricity used; allowing the utility companies to remotely control appliances on the home area network; and allowing electricity consumption to be controlled remotely. Smart meters are combined with wide area communications infrastructure and meter management systems (MDMS) (NETL 2008).

**Table 4.3. Comparison of AMI and Manual Meter Reading and AMR (Developed form van Gerwen et al 2006)**

| | Manual/AMR | AMI |
|---|---|---|
| Pricing | None | Total consumption<br>Time-of-use<br>Critical peak pricing<br>Real-time pricing |
| On Demand Response | Monthly bill | Load control<br>Demand bidding<br>Demand reserves<br>Critical peak rebates |
| Customer Feedback | Turn off appliances manually | Monthly bill<br>Monthly detailed report<br>Web display<br>In-home display |
| Customer Bill Saving | Customer phone calls | Turn off appliances<br>Shift appliances off-peak<br>Manual or automatic control |
| Outages | | Automatic detection<br>Verification of restoration at individual home level |
| Distribution Operations | Use engineering models | Dynamic, real-time operations |

The electric smart meter uses an internally installed modem to exchange communications between the utility company and the customer. Data—such as the quality of the power at the load source, the amount of power being used, the equipment in use, electricity prices, etc.—can be accessed through the use of a communications technology like Bluetooth, Zigbee, Global Positioning System (GPS), an existing internet connection between the smart meter and either existing home appliances or a home display (van Gerwen et al 2006).

Appliances can be controlled directly and the display can be used to show historic energy data, and energy cost and usage.

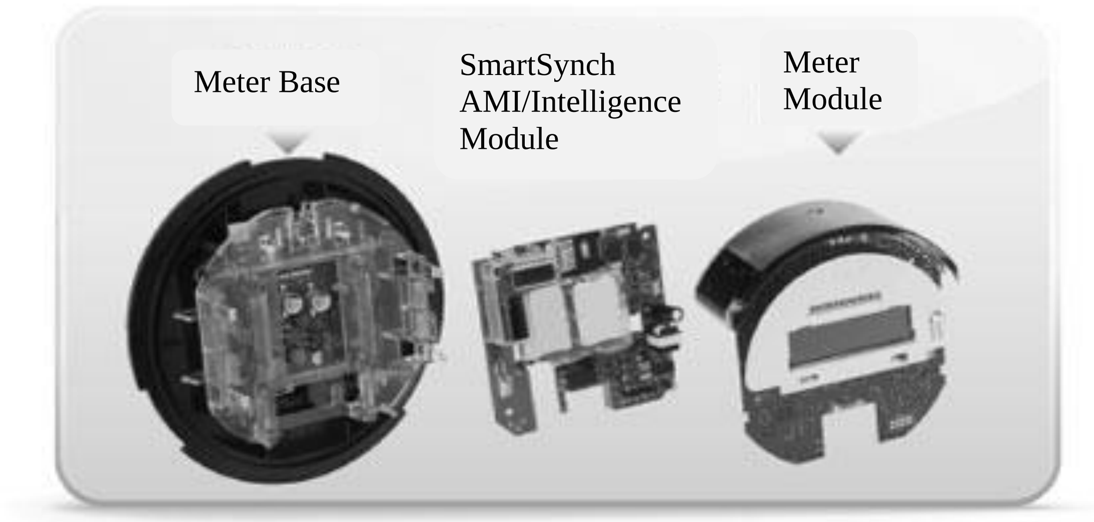
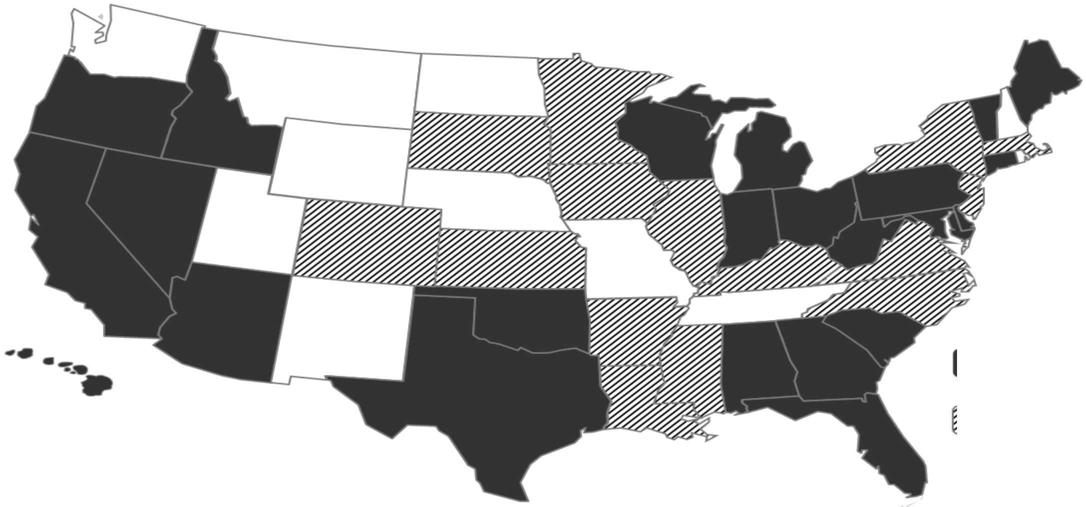



**Figure 4.30. Smart Meter (Source: SmartSynch 2010)**

<u>Deployment Status and Existing Installations</u>

About 70% of utility companies surveyed by GTM Research regarded smart meters as a matter of high or highest priority for installation between 2010 and 2015, and 87% of top management at utility companies had assigned special priority to smart grid initiatives (GTM Research 2010). This survey revealed that smart meter deployment is a priority for most utility companies and that they see smart grid metering as the future of energy distribution.

By the end of 2015, about 60 million smart meters will have been installed nationwide (IEE 2010). Several utility companies in the United States are at various stages of planned deployment for smart meters (Figure 4.35)



Planned deployment for >50% of end users

Planned deployment for <50% of end users

**Figure 4.31. Utility Scale Smart Meter Deployment (Source: World-gen 2010)**

### 4.4.9. Home Area Networks (HAN)

The home area network (HAN), which forms an in-home network of smart appliances, the water heater, the air conditioner, the cable box, etc., networks with a consumer gateway to link to the smart meter (NETL 2008). The HAN eases home automation and control of equipment and appliances, like lighting and security systems; and makes it easy to respond to price signals in the event of dynamic electricity pricing.

Deployment Status and Existing Installations

Home area networks are commercially available, utilizing several existing communication technologies like WiFi and Bluetooth.

### 4.4.10. Home/ Consumer Gateway

The home gateway is the equipment that connects the home area network (HAN) to the smart meter. The consumer portal is a combination of software and hardware that enables communication between utilities and the consumers' end components (EPRI 2005). The gateway enables communication between the HAN and the smart meter, through a communication protocol like Zigbee or Wi-Fi. The gateway can be a standalone system, or installed in a smart meter, a media server or a cable box (Berst 2009).

Using a portal, a customer can receive information on power consumption and its costs in real-time; view energy savings through demand response; report trouble with service; and choose load response prices (EPRI 2005).


**Figure 4.32 – Home Gateway (Source: Smartgridnews 2010)**

<u>Deployment Status and Existing Installations</u>

Several consumer portal technologies are now available. Other portal technologies, like Zigbee and Z-Wave, will be available in 2-3 years. EPRI is conducting substantial work in this area.

### 4.4.11. Other Technologies

There are a number of other sensing and measurement technologies in the research stage. Some of these technologies are summarized in table 4.4.

**Table 4.4. Sample Sensing and Measurement Smart Grid Technologies (Adopted from NETL 2009).**

| SENSING AND MEASUREMENT | | | |
|---|---|---|---|
| **Technology** | **Deployment Status** | **Description** | **References** |
| Dynamic Line Rating Technology | In research | This technology measures the ampacity over overhead transmission lines in real time. There is ongoing research to include line sag, current line capacity and thermal line ratings over lines. | (NETL 2009) |
| Conductor/ compression connector sensor | In research by EPRI | This uses either wireless or broadband technology over power lines (BPL) to measure the dynamic ratings of overhead transmission cables. It measures the temperature differences between the conductor and conductor splices. | (NETL 2007b, NETL 2009) |

## 4.5. ADVANCED CONTROL METHODS

"Advanced Control Methods (ACMs) are the devices and algorithms that will analyze, diagnose, and predict conditions in the modern grid, and determine and take appropriate corrective actions to eliminate, mitigate, and prevent outages and power quality disturbances (NETL 2007d)." ACM technologies will measure, analyze and diagnose data, and autonomously respond to system faults. ACM, in its advanced stage, is expected to collect and monitor grid components and data; analyze the collected data; diagnose and solve emerging problems on the grid; take autonomous actions to rectify anomalies; and provide information for operators to help in decision assistance (NETL 2007d).

This section discusses the following advanced control methods technologies:

- Grid Friendly Appliance Controller
- Substation SCADA

### 4.5.1. Grid Friendly Appliance Controller

Appliances that have been fitted with the Grid Friendly Appliance controller, developed at the Pacific Northwestern National Laboratory (PNNL), sense grid conditions by monitoring the frequency of the system, and provide automatic demand response in times of disruption. Within the North American power grid, a disturbance of 60-Hz frequency is an indicator of a serious imbalance between supply and demand that, unchecked, will lead to a blackout. This computer chip can be installed in household appliances and will turn them off for a few minutes, or even just a few seconds, to allow the grid to stabilize. The controllers can be programmed to autonomously react in fractions of a second when a disturbance is detected. (PNNL 2002)

**Figure 4.33. Grid Friendly Appliances (Source: PNNL 2010)**

Location on Grid

Grid friendly controllers are installed in appliances on the Home area network (HAN).

Deployment Status and Existing Installations

Grid friendly appliance controllers were developed by EPRI and are being introduced by most appliance makers. In April 2009, Whirlpool announced that it will be making all appliances smart grid compatible by 2015. The company set a goal of producing 1 million smart dryers by 2011 (Greenbeat 2009).

### 4.5.2. Substation Information Technology, and Supervisory Control and Data Acquisition (SCADA)

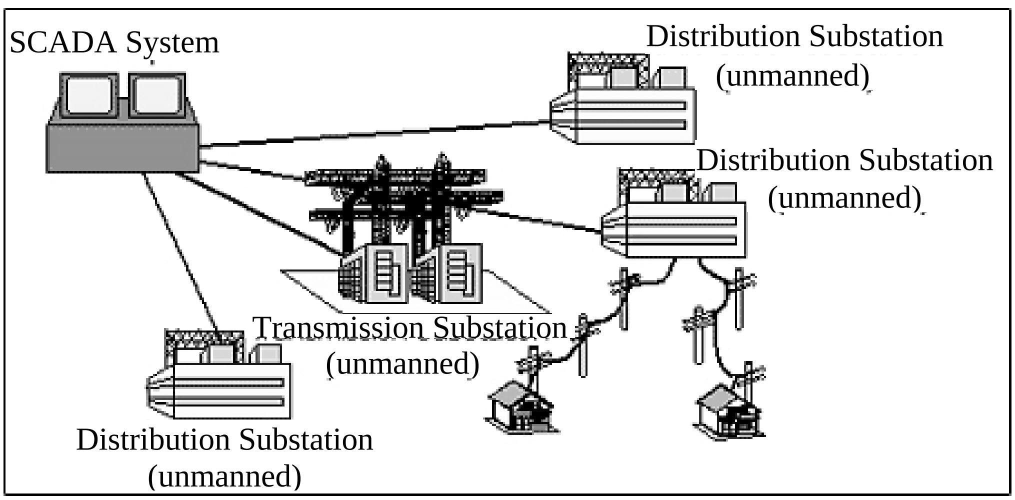



**Figure 4.34. Substation SCADA communications system (Source:Tepco 2010)**

Several companies, including IBM, Intel, Cisco, General Electric, and others, have developed information and communications software, which monitor substations and deliver real time information to the utility companies, using data collected from the different IEDs on the substation. They apply software, like the Geographical Information Systems (GIS), to remotely identify and solve faults in the substation.

Location on Grid

SCADA systems are located grid wide on generation, transmission or distribution feeders.

Deployment Status and Existing Installations

Different SCADA systems are commercially available and utilize different communication technologies.

### 4.5.3. Other Technologies

There are a number of other sensing and measurement technologies. Some of these technologies are summarized in table 4.5.

**Sample of Advanced Control Methods for Smart Grid Technologies (Adopted NETL 2009)**

| ADVANCED CONTROL METHODS | | | |
|---|---|---|---|
| **Technology** | **Deployment Status** | **Description** | **References** |
| Advanced SCADA | Commercially Available | Advanced Control System's PRISM ™ SCADA includes additional functions to the standard SCADA system, like alarms, tagging, load management and load forecasting. | http:www.acsatlanta.com |
| Fault Locator for Distribution Systems | 2-5 years | This system will determine the location of faults on the grid, using travelling waves. This technology is being used on transmission grids but, due to its high cost, it has not been transferable to distribution grids. | (NETL 2007d). (NETL 2009). |
| Weather and Load Forecasting–Numeric Weather Prediction (NWP) | Commercially Available | There are several types of weather and load forecasting systems. The most common ones are all available commercially: Artificial Neural Network (ANN), Fuzzy Logic, Numerical Weather Prediction (NWP), Ensemble and Nowcasting. | (NETL 2009) |
| Grid Shock Absorber | 3-5 years | This concept is based on reconfiguring large interregional networks into asynchronously operated sections. AC sections will be interconnected with HVDC sections of the grid. | (Clark et al 2008) |
| Wide Area Measurement Systems(WAMS) | In service in the West | WAMS continuously monitors power by utilizing synchronized phasor measurements that can stream data in real time. Though PMU networks have been deployed widely by several US utilities, there have been impediments such as cost and reliability in implementing WAMS systems. | (NETL 2009), www.naspi.org/ |
| Distribution Automation | Commercially Available | This technology provides real time configuration of distribution equipment to prevent power outages through the integration of smart sensors and integrated communications. | (NETL 2007d, NETL 2009). |
| Real-Time Voltage Stability | 1-3 years | This deploys reactive power reserves away from critical points in time, in the presence of low load stability margins. These calculations will be derived from PMUs and load characteristics. | (NETL 2009) http://www2.selinc.com/techpprs/6224_SynchrophasorBased_YG_20070607.pdf |

## 4.6. INTEGRATED COMMUNICATIONS

These are fully integrated two-way communication technologies, which will make the grid a dynamic interactive system for power and real-time data exchange (NETL 2007e, Roncero 2008). A variety of communication technologies are utilized in today's grid, but most of these lack full high-speed communications integration. To be most effective, the integrated communications protocol will have to achieve universality, integrity, ease of use, cost effectiveness, standards, openness, and security (NETL 2007e). No universal standards for AMI and Demand Response (DR) exist yet. Several committees and trade groups are collaborating to determine standards for integrated communications systems. The NIST has been charged to develop such standards.

This section discusses the following the integrated communications technologies:

- Broadband over Power Line
- Wireless Technologies
- Miscellaneous Technologies

### 4.6.1. Broadband over Power Line

The idea of broadband over power lines (BPL) has been used over several years by utility companies for remote metering and control (Galli et al 2003). BPL is now being utilized to meet utilities distributed-energy needs, which now include automated meter reading (AMR), AMI and consumer portal applications (NETL 2007e).

### 4.6.2. Wireless Technologies

A variety of wireless technologies that may be utilized for electricity transmission and distribution have been emerging over the past few years. The most common wireless technologies, according to the NETL (2009), are:

- Multiple Address System Radio
- Paging Networks
- Spread Spectrum Radio Systems
- WiFi
- Wimax
- 3Generation Cellular
- Time Division Multiple Access (TDMA) Wireless
- Code Division Multiple Access (CDMA) Wireless
- Very Small Aperture Terminal (VSAT) Satellite

Most of these communication technologies are being used in different applications. Some, like multiple address system radios, are being used by utilities.

### 4.6.3. Miscellaneous Technologies

There are several communication technologies that, even though they are not wireless, could be utilized for grid-integrated communications. According the NETL (2009), these are:

- High Speed Internet
- Power Line Carrier
- Fiber to the Home (FTTH)

- Hybrid Fiber Coax (HFC) Architecture
- Radio Frequency Identification (RFID)

For smart grids to be successful, a fully integrated communication system will need to be employed to enable two-way communication between utility companies and consumers.

## 4.7. IMPROVED INTERFACES AND DECISION SUPPORT

IIDS will be the human interface software of the smart grid. IIDS technologies will convert complicated power system data into easy-to-use information, to aid decision making support. The IIDS will have two-way communication capabilities, where it will be able to send and receive data from the customer, to aid decision-making both at the utility and the HAN (NETL 2007f). When fully integrated into the grid, IIDSs will adopt the use of artificial intelligence to optimize the utilization of grid assets through the reduction of stress on the grid, thereby reducing power outages (NETL 2007f).

### 4.7.1. Geographic Information Systems (GIS)

Geographic information system use will be paramount to the tools for tracking and responding to electric transmission and distribution. GIS can be used in any part of the smart electric grid, from siting analysis of renewable energy sources to AMI installation, monitoring and fault detection (ESRI 2009). The use of GIS is widespread in the T&D industry in several capacities. The next generation of GIS is expected to incorporate 3$^{rd}$ and 4$^{th}$ generation multi-dimensional information with the addition of virtual reality.

Location on Grid

GIS can be utilized grid wide on generation, transmission or distribution feeders for monitoring and tracking.

Deployment Status and Existing Installations

GIS map displays, for special analysis and measurements, are currently available for widespread application over all sectors of the T&D industry. 3-D and 4-D GIS visualization and modeling is expected to be available for commercial applications in about a year (NETL 2009).

## 4.8. SUMMARY

This section provided a detailed overview of smart grid technologies. The technologies were categorized under advanced components, sensing and measurements, advanced control methods, integrated communications, and improved interface and decision support. The technologies were discussed considering a broad overview, their locations on the grid, and the deployment status and any existing installations. For additional details of smart grid technologies, readers can refer to DOE-Smartgridclearinghouse (2010), NETL 2009 and IEEE (2010). This overview of existing and upcoming technologies will help determine the work scope of EC and aid in determining construction opportunities inherent in the adaptation of smart grids.

# CHAPTER 5

# INSTALLATION AND CONSTRUCTION MANAGEMENT ASPECTS OF SMART GRIDS

## 5.1. OVERVIEW

This chapter will explore the installation and construction management (CM) aspects of five smart grid-related technologies: smart substation and smart transformers, automated metering infrastructure (AMI), advanced superconducting transmission cables, energy storage devices, and home area networks (HAN).

These installation and CM aspects will be considered in relation to the categories of Impact on the Overall Power System Design; Location, Planning, Zoning and Environmental Considerations; Product Procurement; Product Installation; Design and Construction of Supporting Components; and Construction Project Management

### Utility Construction Costs

Utility companies are expected to increase investments into transmission, distribution, and generation over the next few years to match demand growth as predicted by the Energy Information Administration (EIA) and the North American Electric Reliability Corporation (NERC). The power-sector companies are forecasted to invest about $11 trillion by 2030 (Stavros, 2007). This forecasted increase will usher in several opportunities for the development and construction industry. However, there has been a significant increase in the construction costs for utility infrastructure over the past few years. According to Chupka and Basheda (2007) these increased costs result from increases in:

- The cost of raw materials,
- The cost of construction field labor, and
- The market conditions for engineering, procurement and construction (EPC).

This increase in the cost of delivering infrastructure projects is seen as a threat to consistent investment into infrastructure construction, especially as governments are cutting their construction budgets worldwide. These cost escalations are expected to continue as demand for utilities infrastructure increases in developing countries and the need to replace aging infrastructure continue in the developed world (Chupka & Basheda, 2007). The skills needed for sound construction management and installation practices will need to be hired at a premium as labor scarcity and material costs keep escalating.

The advent of smart grids has seen several financial inflows into the power sector as discussed in Chapter 3. For the implementation of smart grids to be successful and self-sustaining, best construction and installation practices will be a factor in curbing cost and time over-runs. In this study, the following five main smart grid technologies were identified for in-depth analysis:

1. Smart Substation and Smart Transformer,
2. Automated Metering Infrastructure (AMI),
3. Advanced Superconducting Transmission Cables,
4. Energy Storage Devices, and
5. Home Area Networks.

After interaction and discussion with the members of the ELECTRI-NECA task force and case study participants, these five technologies were chosen for their perceived importance to the success of the implementation of smart grids. In addition, these five technologies were selected to be able to complete this research within the scope of a master's thesis.

In this chapter, the installation and construction management issues of the above technologies will be categorized under the following broad sections for each technology:

1. Impact on Overall Power System Design
2. Location, Planning , Zoning and Environmental Considerations
3. Product Procurement
4. Product Installation
5. Design and Construction of Supporting Components
6. Construction Project Management

Based on the discussion of the chosen categories, the related work scope for electrical contractors will be compiled as a matrix for each technology.

**Location, Planning, Zoning, and Environmental Considerations**

The locational and environmental considerations covered in this section are common to a majority of the technologies to be discussed. Specific siting and environmental considerations will be presented in relation to the various technologies in later sections. The common location, planning, and environmental aspects that apply to all technologies include public opposition, regulatory roadblocks, and environmental constraints.

<u>Public opposition.</u>

Public opposition to siting renewable energy installations, transmission facilities, and, by extension. smart grid components is considered to be one of the main barriers to new development. NIMBY (not in my backyard) and BANANA (build absolutely nothing anywhere near anything) has become part of the national vocabulary (Vajjhala 2006).

For renewable projects to succeed, public participation needs to be sought from inception of the project. The benefit of a large public work cannot be fully realized without public trust and support (Gale & O'Driscoll, 2001). Due to negative views of aesthetics and environmental problems, communities who are seemingly environmentally conscious are more likely to accept traditional energy facilities than renewable installations.

Regulatory Roadblocks**:**

Regulation of renewable energy and smart grid components is fragmented over several agencies and departments. There is no standardized permitting and licensing process, and project reviews can be done under the jurisdiction of federal, state, and local governments. As an example, electricity transmission siting is regulated by the states and some local authorities, while pricing is regulated by the federal government through the Federal Energy Regulatory Commission (FERC). Regulating the siting of transmission lines is the responsibility of the state; however, if the transmission lines cross state lines then each individual state needs to approve the siting according to its own laws. Additional federal approvals are needed if the lines cross federally owned or controlled lines (Mayer & Sedano, 2006). These federal approvals, depending on the type of federal land the transmission line is situated on, can be obtained from any one of the following entities: the FERC, the Bureau of Land and Management under the Environmental Protection Council (EPA), or the US Forest Service. Some projects are delayed unnecessarily due to regulators' lack of familiarity with renewable energy installations and smart grid components technologies (Vajjhala 2006).

Environmental Constraints**:**

Environmental constraints arise as a result of the fact that all construction projects have some effect on the environment, and transmission/distribution lines and renewable energy installations are no exception. The constraints on the environment can be categorized under land use, electric and magnetic fields, and air emissions (Gale & O'Driscoll, 2001; Vajjhala, 2006). Renewable energy sources are highly dependent on the available resources; for example, a wind farm will have to be sited where the wind blows. Even though it might meet all other necessary requirements, this wind farm cannot be replaced with a solar installation if the original proposal fails (Vajjhala 2006).

Renewable projects are also constrained by their access to supporting transmission lines. Most of the prime areas for wind turbines are in the upper Midwest where transmission lines are limited. The site-specific nature of renewable resources might require some compromise when choosing between the highest quality resource location and the location with the most reasonable cost due to the proximity of infrastructure elements such as transmission lines (McVeigh et al. 1999).

## 5.2. ENERGY STORAGE DEVICES

Energy storage devices (ESD) are seen as major components in the success of smart grids. Most ESD installations are pilot programs. However, these installations are becoming increasingly widespread over the country. The installation processes considered for ESD in this section are mostly for distribution feeder ESD, but are relevant for most ESD. Some storage devices such as CAES and pumped hydro are too large to fit on distribution feeders. Thus, only a  few storage technologies like lead-acid batteries, sodium sulfur (NaS), flywheels, and the like can be used for distribution installations.

On the distribution feeder, the distributed voltage from the ESD should be equivalent to the line ratings to and from the distribution feeder (Nourai, 2007). The installation of ESD on distribution feeders includes the installation of the ESD together with a power conversion system and a transformer to smooth incoming and outgoing power. There is ongoing research to adopt larger forms of distribution capable battery systems for the transmission feeder.

### 5.2.1. Impact on the Overall Power System Design

The widespread use of ESD on the grid will enable the storage of power during off-peak periods for demand when demand is at its peak.  This will enable utility companies and consumers to reduce electric costs through the reduction of the size of generation plants built specifically to meet peak demand requirements.

### 5.2.2. Location, Planning, Zoning, and Environmental Considerations

As with most new technologies, ESD have no history to guide regulators in their installation and operation. There are few regulations explicitly for ESD installation (EAC 2008). ESD have the ability to operate as a generation source when used for generation shifting and for power quality augmentation. These multiple roles have also led to confusion about how ESD should be regulated (EAC 2008).

Nevertheless, the siting and location of ESD are critical in the installation of a storage device. In times of emergency on the grid, the storage battery will be expected to provide emergency power to serve critical infrastructures. This makes installing the ESD to withstand disaster situations like floods, storms, and earthquakes critical.

Installed batteries are unusually installed near or in substations. The site selection requirements are similar to those used for substation installation. The requirements are also dependent on the type of ESD selected for installation. The following should be adhered to in selecting location and site for the installation of ESD (IEEE 1996; IEEE 1997; Nourai, 2007):

- The charging grid source should be as practically close to the ESD as possible .
- The allocated land for the ESD should allow for future site development and expansion.
- The site should be as level as possible or the foundation should be level as possible to avoid the tilting of the cells.
- The location should have the minimum amount of effects from vibrations as possible.

### 5.2.3. Product Procurement

<u>Battery Packaging and Transportation</u>:

Procuring batteries is one of the most critical parts in the installation of an ESD. Energy storage devices are considered sensitive electrical equipment, careful handling and storage is required for safe delivery. The transportation of batteries can be done via the following methods:

- Air,
- Rail,
- Water, and
- Road.

The packaging of batteries should be done to prevent vertical and horizontal movement during shipping. Vibrations should be prevented during the shipping process. The cells should be protected from the elements throughout the shipment period and storage.

Packaging Procedures (IEEE 1996, Nourai 2007*:*

The most common way to transport battery cells is to stack them on wooden pallets and place them in shipping cases for easy shipment. The cell modules should be attached firmly to the shipping pallets before encasing to prevent movements during transportation.


**Figure 5.1. Packaging of NaS Batteries in Container for Shipping.**
*(Source: Nourai 2007)*


**Figure 5.2. Delivery and unloading of Battery Cell Shipping Cases on Site**
*(Source: Nourai 2007)*

Receiving (IEEE 1997)

All cells should be inspected visually after receiving. If damage is apparent, a more detailed inspection should be done for the entire shipment consignment. Cells with defects, such as cracked jars or loose terminals, should be returned for repair or replacement. All received cells should be stored in a dry place away from the elements. The manufacturer's recommendations for storage and handling should be adhered to and no cells should be stored over the recommended time without charging.

### 5.2.4. Product Installation

Installation Standards

Existing installation guides are:

- IEEE Standard 450-1995, IEEE Recommendation Practice for Maintenance, Testing and Replacement of Vented Lead Batteries for Stationary Applications (ANSI).
- IEEE Standard 484-1996, IEEE Recommended Practice for Sizing Lead Acid Batteries for Stationary Applications.
- IEEE Standard 485-1997, IEEE Recommended Practice for Installation Design and Installation of Vented Lead Acid Batteries for Stationary Applications.
- IEEE Standard 1184-1994, IEEE Guide for Selection and Sizing of Batteries for Uninterruptible Power Systems (ANSI).
- ANSI/NFPA 2011 National Electric Code.
- IEEE 1115-1992, IEEE Recommended Practice for Sizing Large Nickel-Cadmium Batteries for Stationary Applications.
- IEEE 1100-2005 Power and Grounding Sensitive Electronic Equipment (ANSI).
- IEEE C2 National Electric Safety Code.

Battery Installation

The installation of the cells should follow all manufacturers' instructions. All terminals, posts, and connection hardware should be free from all dirt and corrosion. The cells should be installed in a sequential order to enable easy identification during operation and maintenance (IEEE 1997).

**Figure 5.3. Delivery and Installation of Battery Cell Enclosure on Foundation**
*(Source: Nourai 2007)*

**Figure 5.4. Installation of PCS on Foundation Pads**
*(Source: Nourai 2007)*

**Figure 5.5. Installation of Battery Cells into Cell Enclosures**
*(Source: Nourai 2007)*

There are no specific standards governing the installation of all energy storage devices. There are, however, some installation guides for the installation of old technologies sich lead acid storage systems. The IEEE, in recognizing this limitation, has commissioned a working group (P2030.2) to develop standards for integrating energy storage devices into smart grids (IEEE SmartGrid 2011).

Power Conversion System

The power conversion system (PCS), which is usually installed with the ESD, converts AC power to DC to charge the ESD and controls the discharge of stored power back into the grid. The foundation and installation requirements for PCS are similar to those for ESD.

**Figure 5.6. Installation of the Power Conversion System**
*(Source: Nourai 2007*)

### 5.2.5. Design and Construction of Supporting Components

**Foundations**

The foundations for transformers can be either precast or cast in place. The foundation pads should be designed to accept all normal applied and imposed loadings without damage or settlement. Foundation should be designed to satisfy soil conditions on site. The pad layout should be done with accurately and must satisfy all utility, local, and state ordinances. The pad design should be done by a profession engineer. The pad surface should be slightly sloped to prevent water collection at transformer base. The foundation can be precast or cast in place.


**Figure 5.7. Layout and Preparation for Foundation Slab.**
*(Source: Nourai 2007)*

**Figure 5.8. Foundation Pad Showing Steel Base**
*(Source: Nouria 2007)*

## Battery Enclosures

The battery enclosures should be designed according to the requirements of the battery system. The enclosures should be able to keep the elements out of other cells and should meet the ventilation requirements of the manufacturers. The enclosures should be sturdy enough to contain the battery cells. The manufacturing and design should be in accordance with the manufacturers' operational requirements for heat and ventilation.

### 5.2.6. Construction Project Management

Refer to construction management for substation and smart transformers and Table 5.5.

### 5.2.7 Electrical Contractors Scope of Work

A work scope was developed for EC for ESD. This work scope was developed from literature and verified by the ELECTRI-NECA task force. The work scope for ESD includes:

- Procuring and installing energy storage devices,
- Installing power conversation systems,
- Installing measurement and communication components,
- Installing step-up transformers,
- Building battery control rooms,
- Monitoring connections to distribution monitoring systems (DMS),
- Testing and commissioning ESD, and
- Providing technical support to owners.

**Table 5.1a. Checklist for Construction Management and Installations (Overall Power System Design and Location, Planning, Zoning, and Environmental Considerations)**

| | Construction Management and Installation Energy Storage Devices | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **Overall Power System Design** | | | |
| Effect on Overall Power System Design | Power System Design (Gomez et al., 2010)<br>• Will limit the size of generation plants.<br>• Help to meet power demands in peak demand times.<br>• Help meet power quality demands.<br>• Smoothing out load peaks.<br>• Provide energy as back up during instantaneous primary energy shut downs.<br>• Enable the widespread deployment of wind and solar installations as power can be stored during off-peak periods. | Low | |
| **Location, Planning , Zoning and Environmental Consideration** | | | |
| **Permits and Approvals**<br>• Permitting<br>Environmental enhancement and site restoration<br>• Safety Plans<br>– Safety manuals and procedures grounding practices<br>– Daily job hazard assessments<br>• Environmental Plans<br>– Noise Control<br>– Erosion and Sedimentation Control | | High | Owner<br><br>EC |

**Table 5.1b. Checklist for Construction Management and Installations (Product Procurement)**

| | Construction Management and Installation Energy Storage Devices | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **III. Product Procurement** | | | |
| • ESD Procurement<br><br>• ESD Lead Time<br><br>• Transportation Requirements for ESD Delivery | Most common transportation methods<br>Truck, Railroad, Sea Carrier, and Air Carrier<br><br>Lead time for ESD depends on complexity of design, size, worldwide demand for product, vendor, etc.<br><br>Major suppliers:<br>NaS – NGK Insulators LTD Japan<br>Flywheels - Beacon , VYCON<br>Lead Acid Batteries – GNB Power , Delco<br>Lithium Ion Batteries – SAFT, A123 Systems<br>Vanadium Redox Batteries- Prudent Energy<br>Zinc Bromide – ZBB | High | Owner/EC /Product Vendor |
| Crane Procurement | Cranes should be able to move batteries without damage. The operator's experience is of a high priority | Normal | EC |
| Access Roads and Transportation on Site<br>• Site Preparation<br>• Erosion Control and Fencing<br>• Grading and Road Improvements<br>• Crane Deployment On Site<br>• Trenching and Cable Laying | | | EC/Subcontractor |
| Inspections and Commissioning | Performed under NEC requirements | High | EC/Subcontractor |

**Table 5.1c. Checklist for Construction Management and Installations (Product Installation)**

| | Construction Management and Installation Energy Storage Devices | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| 1 | 2 | 4 | 5 |
| **IV. Product Installation** | | | |
| Installer /Technician Qualifications | ANSI /NETA ETT 2000 | | |
| Installation Code and Standards | • IEEE Standard 450-1995, IEEE Recommendation Practice for Maintenance, Testing and Replacement of Vented Lead Batteries for Stationary Applications (ANSI)<br>• IEEE Standard 484-1996, IEEE Recommended Practice for Sizing Lead Acid Batteries for Stationary Applications<br>• IEEE Standard 485-1997, IEEE Recommended Practice for Installation Design and Installation of Vented Lead Acid Batteries for Stationary Applications<br>• IEEE Standard 1184–1994, IEEE Guide for Selection and Sizing of Batteries for Uninterruptible Power Systems (ANSI)<br>• ANSI/NFPA 2011 National Electric Code<br>• IEEE 1115–1992, IEEE Recommended Practice for Sizing Large Nickel-Cadmium Batteries for Stationary Applications<br>• IEEE 1100–,2005 Power and Grounding Sensitive Electronic Equipment (ANSI)<br>• IEEE C2 National Electric Safety Code | | EC |
| Requirements on Site<br>• Site Preparation<br>• Erosion Control and Fencing<br>• Grading and Road Improvement | | Normal | EC/Subcontractor |

\

**Table 5.1c. Checklist for Construction Management and Installations (Product Installation) (Continued)**

| | **Construction Management and Installation Energy Storage Devices** | **Level of Importance (EC)** | **Responsibility of** |
|---|---|---|---|
| **V. Product Installation** | | | |
| Requirements on Site<br>• Site Preparation<br>• Erosion Control and Fencing<br>• Grading and Road Improvement | | Normal | EC/Subcontractor |
| Grounding ESD | Grounding practices should be clearly illustrated and well documented as part of company safety practices.<br>All project grounding design adhered to and strictly followed as stipulated by manufacturers | High | EC |
| Quality Control | Visual inspection of ESD cells delivered to site<br>Specific inspection methods for components of the ESD<br>Ensure batteries are well ventilated<br>Restrict all unauthorized persons from battery area (IEEE 1997) | High | EC |
| Safety | Company safety manuals and procedures well documented<br>EMR and DART records<br>Periodic safety training for labor<br>Daily job safety and hazard assessments and tailgate meetings | | |

**Table 5.1d. Checklist for Construction Management and Installations**
**(Design and Construction of Supporting Components and Construction Project Management)**

| | Construction Management and Installation Energy Storage Devices | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **VI. Design and Construction of Supporting Components** | | | |
| Foundations<br><br><br><br><br>Battery Enclosures | Foundation pad layout should satisfy local and state ordinances<br>Anchor bolts should be accurately aligned<br>Steel bases for the foundation should be well aligned to receive battery enclosures<br>Battery enclosures and racks should be embedded using approved fastening techniques<br>When batteries are installed in the building, caution should be taken in anchoring the enclosures to the walls and the floor as this might cause stress from vibration (IEEE 1997) | High | EC CM Subcontractor |
| Anchor Materials | Size length must meet ASTM A 36 (ASCE 2008) | High | EC |
| **VII. Construction Project Management** | | | |
| Project Team Qualifications and Availability | Team members and qualifications should be clearly stated and presented to owner | High | EC |
| Project Estimate | Attention given to complexity of installation, contract requirements, project duration, commodity price escalation, and market conditions. | High | EC |
| Project Schedule | Provide milestone, phase, monthly, and daily look-ahead schedules | High | EC |
| Project Controls | Bar Charts<br>S Curves<br>Earn Value Analysis | High | EC |
| Quality Assurance Plans | Warranty for work performed encouraged<br>Warranty on all equipment documented | High | EC |
| Safety | Company safety manuals and procedures well documented<br>EMR and DART records<br>Periodic safety training for labor<br>Daily job safety and hazard assessments and tailgate meetings | | |

**Table 5.2. Work Scope of Electrical Contractors for Energy Storage Devices**

| Work scope of Electrical Contractors for Energy Storage Devices | | |
|---|---|---|
| **Self-Performed** | **Subcontractors** | **Consultant** |
| • Procuring and Installing Energy Storage Devices<br>• Installation of Power Conversion Systems<br>• Installing Measurements and Communication Components<br>• Installation of Step-Up Transformers<br>• Battery Control Rooms<br>• Connection to Distribution Monitoring Systems (DMS)<br>• Testing and Commissioning ESD<br>• Consulting and Training<br>• Project Management<br>• Development of Specifications | **Siteworks**<br>• Excavating and Backfilling<br>• Stripping and Clearing<br>• Grading<br>• Drainage<br>• Fencing<br>• Access Roads<br>• Communication Systems Installations<br>• Erosion and Sedimentation Control<br><br>**Concreteworks**<br>• Foundations<br><br>**Environmental Planning**<br>• Land Reclamation<br>• Erosion and Sedimentation Control | **Consultants**<br>• Environmental<br>• Design<br>• Communication Systems and Information Technology<br>• Workforce Training<br>• Surveying and Right-of-Way Engineering<br>• Community Education Plans |

## 5.3. ADVANCED SUPERCONDUCTING TRANSMISSION CABLES

The introduction of HTS conductors to the market is one of the major changes in the electricity transmission and distribution industry. HTS conductors have not yet gained mainstream acceptance due to their limited availability, high cost, and the lack of installation experience among line workers.

### 5.3.1. Overall Power System Design

The introduction of advanced superconducting transmission cables will revolutionarize the way power systems are designed. A power system is designed with transmission losses as the primary design factor. The introduction of superconducting cables changes this design paradigm. This is because, in some super-conducting cables, transmission losses approach zero or are almost negligible. As such, the primary design factor might shift to other areas of consideration such as economic constraints, aesthetics, environmental effects, and the like. (Case Study 16, 2011).

### 5.3.2. Location, Planning, Zoning, and Environmental Considerations

Transmission lines affect the environment in several ways, be it the right-of-way clearance through forests and agricultural lands or erosion problems from construction activities. According to PSC of Wisconsin (2010), the effects of transmission lines on the environment can impact a variety of areas:

- Aesthetics,
- Agricultural lands,

- Airports and airstrips,
- Archeological and historical sites,
- Electric/magnetic fields,
- Endangered species,
- Noise,
- Property owner impacts,
- Radio and television reception,
- Recreation areas,
- Safety,
- Stray voltage,
- Waterways,
- Wetlands, and
- Woodlands.

During construction, mitigating procedures and processes need to be employed to reduce environmental effects. Siting difficulty has been one of the main reasons why transmission lines have not been built to keep up with demand in the past few years (Casper & Wellstone, 1981; Pierobon, 1995; Abel 2005; Vajjhala & Fischbeck, 2006). Although the United States has the largest and one of the most reliable electricity systems in the world, electricity transmission and distribution expansion has not matched growing demand (CECA/RF, 1990; DOE, 2002; EEI, 2002; Hirst and Kirby, 2001). Many Americans would like to see the adaptation of renewable energy solutions; however, there is still a lot of community resistance when such facilities are sited.

Renewable energy projects have, at times, provoked more opposition than one might have thought, mostly due to its being located in isolated and pristine places near mountains, coastal water, or plains.

The most commonly identified problems with siting renewable energy or transmission lines fall into these obstacles to the process of finding locations for new facilities include public opposition; environmental, topographic, and geographic constraints; interagency coordination problems; and local state and federal constraints (Gale & O'Driscoll 2001; Vajjhala 2006; Vajjhala & Fischbeck 2006).

**Transmission Permitting Process**

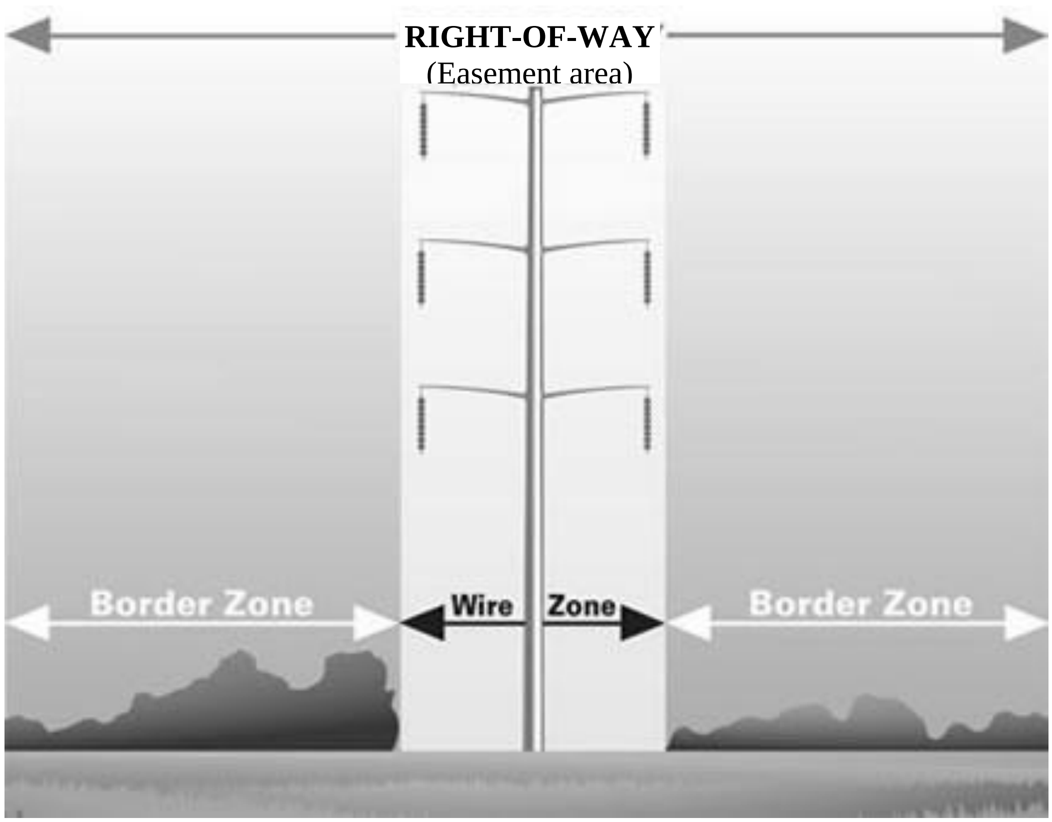



**Figure 5.9. Right of Way**
*(Source: ATC 2011)*

The permitting and siting of transmission lines is usually seen as a major impediment to transmission development in the United States. There have been several attempts to rectify and streamline the permitting process and the requirements needed for transmission installations. Aside from the delays caused by the transmission siting process, transmission costs make up about 10% of the average electric bill (DOE 2002).

In the EPACT (2005), the Federal Energy Regulatory Commission (FERC) was authorized to consider a transmission siting application if the permitting state had not worked on the transmission application in a year or failed to recognize the interstate benefits of the project (FERC 2011). Also, the EPACT 2005 allowed three or more contiguous states to form interstate pacts to facilitate transmission line siting within the states. These laws were passed to encourage the speedy processing of transmission projects through state agencies. However, this has not been the case (Case Study 15, 2011).

The voltage of the transmission line determines the width of the right-of-way. The right-of-way is usually about 100–200 feet wide and must conform to all vegetation management standards (FERC 2011). In the state of Michigan, the Michigan Public Services Commission (MPSC) has oversight over the siting of transmission lines in the state. This authority is governed under the Michigan Electric Transmission Line Certification Act (Davies et al., 2010). The utility companies have to present an application to the MPSC within five years of commencing planning for a major transmission line. The application must contain a description of the project, the transmission route, and an evaluation of alternative routes. A public hearing will be heard before a certificate is issued for construction to proceed (Davies et al., 2010).

An expedited certificate can be issued for transmission lines for the transportation of electricity generated from wind energy as a result of Michigan Public Act 295 (2008).

### 5.3.3. Product Procurement

The company contacted during the case study was not installing HTS conductors on their main transmission lines. This is due to problems the company had with the new technology. These problems included longer lead times and the unavailability of conductors on the market; hence, it was not a good fit in times of emergency repairs, which is a major factor in determining the products used. They were also not conversant on the topics of the installation equipment and processes needed for HTS installations

**Contract Delivery Systems**

Transmission and utility companies use several delivery systems to procure transmission and distribution contracts. Transmission contracts can either be a guaranteed maximum price (GMP), or time, and material arrangement, where the owner provides all materials and the contractor is paid for installation time, or a traditional competitive bid. The delivery system will be determined on the owner and his experience procuring projects (Case Study 5, 6, and 14, 2011).

### 5.3.4. Product Installation

**Installation Standards**

Transmission conductors are installed following IEEE Standard 524-2003 (IEEE 2004).

**Installer / Technician Qualifications**

There are no nationally recognized smart grid technician certifications. Smart grid technology requires a spectrum of skilled trade certifications for traditional line men and substation installers. The substation wiremen should have at least completed a substation wireman apprenticeship or equivalent training, or should be graduates of electric technician programs from community colleges and technical schools that prepare students for current entry-level work as substation technicians. One existing certifications for traditional linemen is the American National Standards Institute and International Electric Training Association (ANSI/NETA ETT) certification.

**Foundation Types**

The choice of foundation is usually determined by a structural engineer. The foundation type is dependent on the loading and type of support members used. The most common types of foundations used for pole and lattice construction are:

- Gravity foundations using reinforced concrete slabs,
- Pile foundations with concrete slabs, and
- Sheet pile foundations with concrete slabs.

The case study transmission company contacted during this study was skeptical of the installation processes and equipment needed for HTS cables. The installation processes illustrated in this section are adopted from the 3M Corporation's handbook on ACCR installation and maintenance.

**Installation Equipment (3M 2011)**

Drum pullers are used in the stringing procedures of ACCR conductors. This is done in conjunction with a back-tensioning device such as a bullwheel tensioner.

According to the 3M Corporation, this device can be used with any installation of ACCR conductors.

**Figure 5.10. Drum Pullers for Stringing ACC Conductors**
*(Source: 3M 2011)*

Bullwheel Tensioners

Bullwheel tensioners have been used for the installation of ACCR conductors. The manufacturer recommends the use of a larger-sized bullwheel diameter when stringing this type of conductor.

**Figure 5.11. Bullwheel Tensioners**
*(Source: 3M 2010)*

Stringing Blocks

A combination of high-stringing tension with a small bend radius can damage the inner core wires of the composite conductor. Larger diameter stringing blocks are required when installing ACCR. A roller array block is required at all break-over towers and high running angles

**Figure 5.12. Stringing Block**
*(Source: 3M 2010)*

Socket Splice

A socket splice, also known as a basket grip or Kellem grip, can be used to string ACCR conductors. The double swivel connection is recommended for use with the socket splice to reduce any twisting of the conductor during the tension stringing operation. The conductor should not be used if it is under the socket splice. Bands should not be used on the end to hold the socket splice, as this can cause damage to the composite cores in the conductor. Friction tape should be applied over the end of the socket splice and the conductor. Figure 5.20 shows a typical socket splice in use.

**Figure 5.13. Socket Splice**
*(Source: 3M 2011)*

Cable Cutters

Cable cutters are used to cut ACSR or AAAC conductors in order to prevent the conductor strand from unstranding.

Conductor Grounding Clamps

Grounding clamps that are used on traditional conductors are compatible with the ACCR conductor. Grounding clamps should be sized appropriately to fit the conductor being installed.

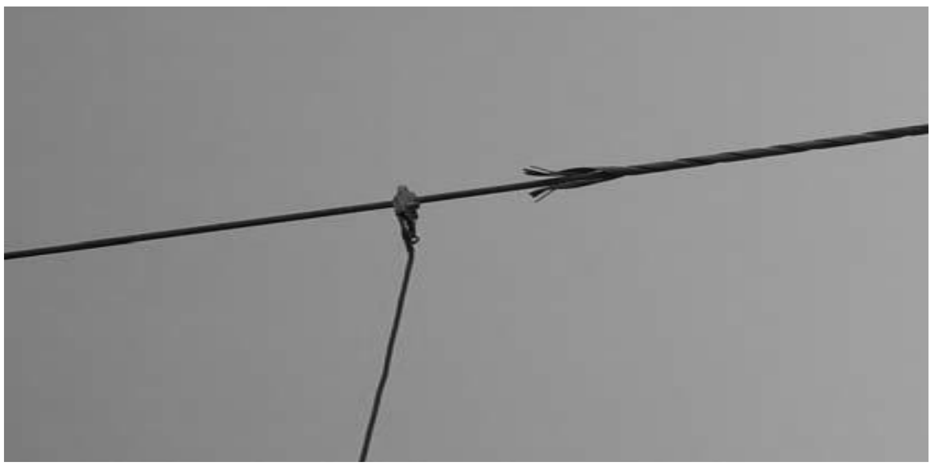


**Figure 5.14. Conductor Grounding Clamp**
*(Source: 3M 2011)*

Running Grounds

Running grounds or traveling grounds can be used when installing ACCR conductors. A properly sized running ground should be used when installing the ACCR conductor.

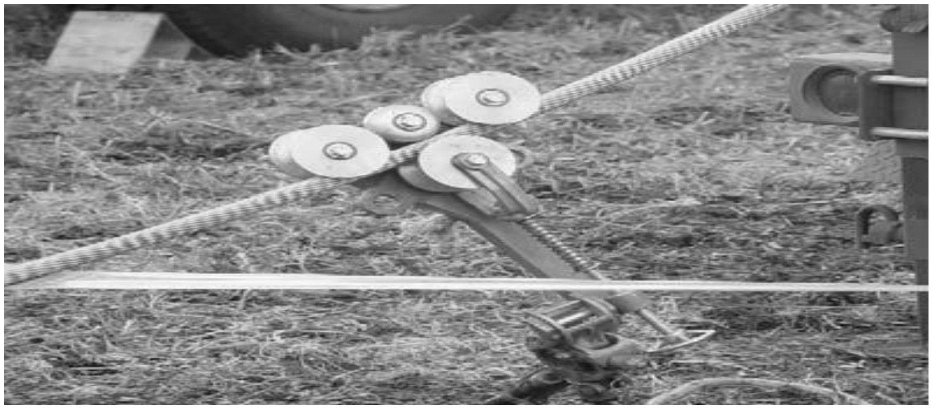


**Figure 5.15. Running Ground**
*(Source: 3M 2010)*

Reel Stands

Standard reel stands may be adopted to hold the reels of ACCR conductors during the stringing operation. Reel stands, combined with bullwheel tensioners can be been used to ensure proper back tensions on the ACCR conductor. It is recommended by manufacturers that a bullwheel tensioner along with a reel stand be used to maintain proper stringing tensions.

Chicago Grips

The use of Chicago grips is prohibited on ACCR cables.

## Insulator and Hardware Assemblies

Cable Stringing

There are four main methods of stringing overhead transmission conductors (Caulkins, 1987):

1. Slack stringing,
2. Semi tension,
3. Full Tension, and
4. Helicopter.

In the installation of composite cables, this research focused on tension stringing as there was little to no information on the other stringing methods. According to the 3M Corporation (2011), similar installation equipment used for traditional steel cables can be used in the installation of ACCR cables.

Tension Stringing

The stringing procedure recommended for use when installing ACCR conductors is the tension stinging method. This involves pulling the ACCR conductor under tension. The cable should not be allowed to drag on the ground. The "slack" stringing procedure is not recommended for ACCR cables. This involves the pulling of the conductor out on the ground by means of a pulling truck or placing it out on the ground by dispensing the cable from a moving vehicle holding the reel stand.

According to manufacturers, it is important to maintain sufficient back tension when installing the ACCR conductor so as not to allow the conductor to drag onto the ground or any support structures that might be used. Nevertheless, too much back tension combined with small bend radii such as small diameter stringing blocks can cause damage and destruction to the inner composite core wires.

Major equipment required for tension stringing includes reel stands, tensioners, drum pulleres, large stringing blocks, socket splices, and conductor grips such as DG grips or preformed dead ends.

Sagging Procedures

Methods of sagging that have been used on the ACCR include line-of-sight measurements and rope or wave reflection sagging. Sagging procedures for ACCR conductors are very similar to that of any other conductor. Whether or not a compression type dead end is to be used on the conductor, the conductor grip must be placed on the conductor at least 12 to 15 feet from the connection point to the insulator string. After the final sag tension is set, the dead ends can be installed onto the ACCR. With the initial placement of the conductor grip at 12 to 15 feet, this should allow enough slack in the conductor to maneuver it and apply the dead end assembly.

Dead Ending Procedures

– Compression Dead Ends

Compression-type dead ends have successfully been used in the installations of ACCR conductors. These types of compression dead ends are specifically designed to grip not only the outside aluminum strands but also to grip the core wires of the ACCR separately. Therefore, the installation steps of the dead end consist of a two-step compression procedure.

After the final sag tension of the conductor is established, a measurement is made to determine where the dead ends will be connected to the insulator string. The cable is then cut at this point. By using a cable strand-trimming device, also known as a cable circumciser, the outer layers of aluminum are removed. It is very important to not nick the composite wires while trimming the aluminum layers.

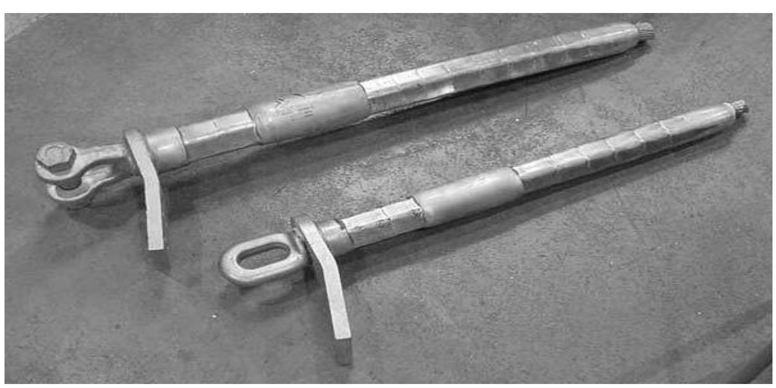


**Figure 5.16. Compression Dead End**
*(Source : 3M 2011)*

– Compression Splices

Compression-type conductor splices have successfully been used in the installations of ACCR conductors. These types of compression splices are specifically designed to grip not only the outside aluminum strands but also to grip the core wires of the ACCR separately. Therefore, like the compression-type dead end assembly, the installation steps of the full tension splice consist of a two-step compression procedure. It is recommended that the minimum distance from a splice location to a dead end or suspension tower should be 50 feet (15M). The two ends of the conductor that are going to be spliced are brought together and held by the use of a chain hoist and two conductor grips. Conductor grips must be spaced out so that the installation of the splice does not interfere with the conductor grips themselves.

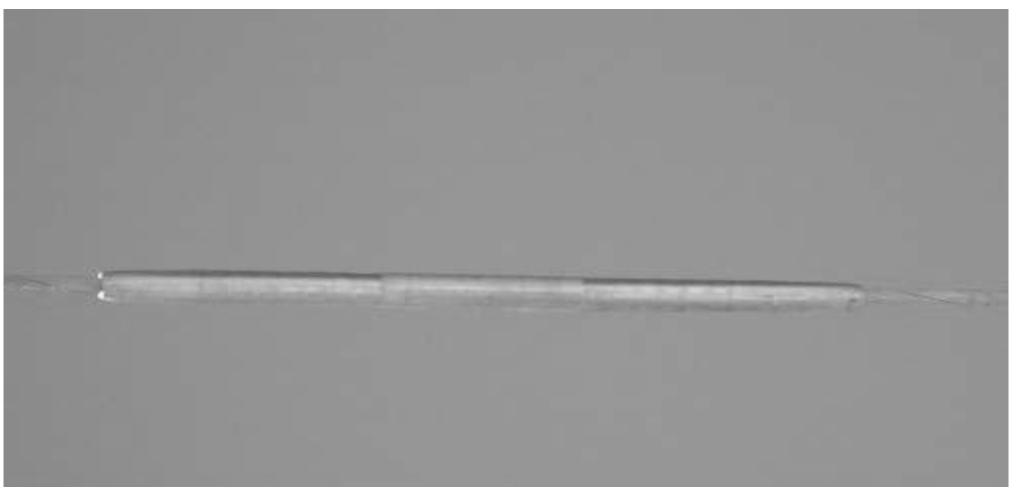


**Figure 5.17. Full Tension Compression Splice**
*(Source : 3M 2011)*

**Miscellaneous Components**

<u>T-Tap Connectors</u>

T-Tap connectors have been used in the installation of ACCR conductors. These types of connectors can be installed directly over the outside layer of the ACCR. These types of connectors usually have a breakaway torque bolt that automatically sets the needed torque specification of the hardware.

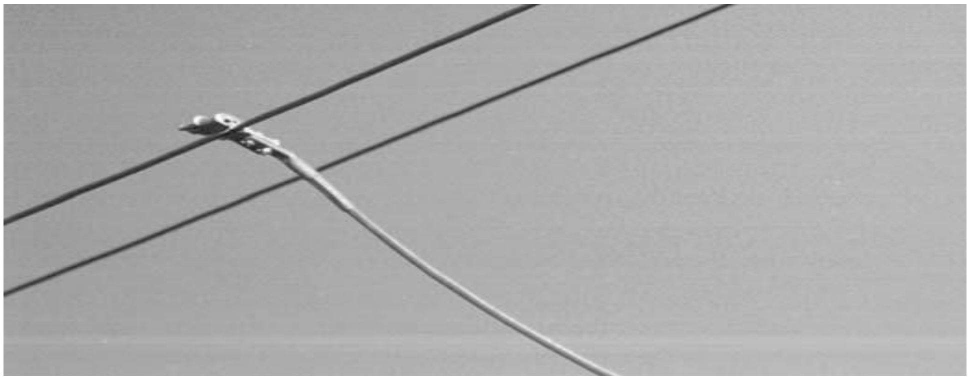


**Figure 5.18. Pad Tap Connector**
*(Source : 3M 2011)*

Vibration Dampers

Vibration dampers have been successfully used in the installations of ACCR conductors. Typical vibration dampers have a breakaway torque bolt that ensures the proper torque setting when installed on the conductor. Tests have shown that the clamps used with the vibration dampers do not cause any damage to the composite core wires of the ACCR.

**Figure 5.19. Vibration Dampeners**
*(Source : 3M 2011)*

Bundle Spacers

Spacers are qualified for use on ACCR conductors on bundled installations. The two spacer halves are connected together at the proper location of the bundle conductor for each span. The two halves are connected using a single breakaway bolt to ensure that the two halves are connected and tightened to the correct torque. The final step of the spacer installation involves applying a single layer of protector rods over the conductor and centered over each side of the connection point of the spacer to on the conductor.

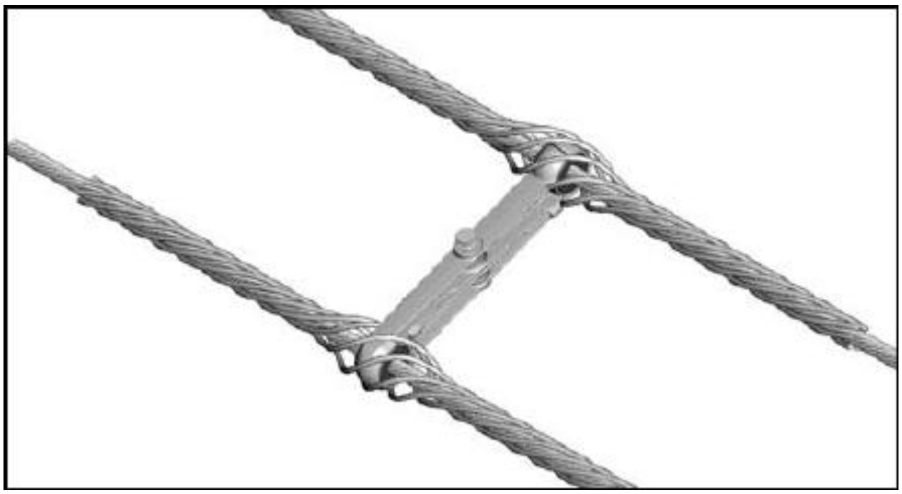


**Figure 5.20. Bundle Spacer Installation**
*(Source : 3M 2011)*

### 5.3.5. Design and Construction of Supporting Components

#### Types of Transmission Towers

Transmission towers come in several types depending on the structural loads to be carried, land layout, distances to be spanned, local regulations, and the like (FERC 2011). The most commonly used types of transmission towers are shown in the figures on the next page.

**Figure 5.21. Double Circuit 138kv on Wood**
*(Source ATC 2011)*

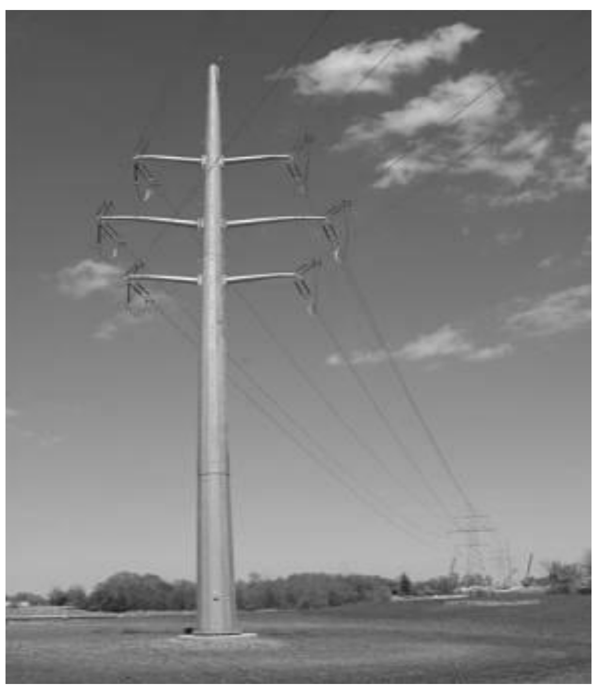


**Figure 5.22. Double Circuit 138kv on Galvanized Steel**
*(Source: ATC 2011)*

**Figure 5.23**. **38-Kilovolt Single-Circuit Line on Weathering Steel**
*(Source: ATC 2011)*

**Figure 5.24. H-Frame Wood Structure**
*(Source: ATC 2011)*

**Figure 5.25. Double-Circuit 138-Kilovolt Line On Steel Lattice Tower**
*(Source: ATC 2011)*

**Figure 5.26. 138-Kilovolt Steel H-Frame**
*(Source: ATC 2011)*

**Figure 5.27. 345-Kilovolt, Double-Circuit Line on Single Poles**
*(Source: ATC 2011)*

**Design of Latticed Steel Transmission Structures (ASCE 10-97)**

The design of towers and lattice support poles is governed by AESC standards. Design factored loads are multiplied by load factors specified by the National Electric Safety Code (IEEE 2007) and Guidelines for Transmission Line Structural Loading (AESC 1997).

This covers basic provisions for safeguarding persons from hazards arising from the installation, operation, or maintenance of conductors and equipment in electric supply stations and overhead and underground electric supply and communication lines. It also includes work rules for the construction, maintenance, and operation of electric supply and communication lines and equipment according to the National Electrical Safety Code.

Minimum Sizes

A minimum thickness of 1/8th inch for members and 3/16th inch for connection plates is suggested.

Tolerances Established By Suppliers

Tolerances contained in ASTM Specification A6 should be used as a guide

The commonly used fasteners for lattice transmission towers are ASTM A394 for bolts and A563 for nuts.

**Welding**

Welding procedures shall comply with ANSI / AWS D1.1.

**Direct Embedded Structures**

Structures designed for direct embedment is recommended to be tested in a two part program:

1. Soil properties.
2. Above-ground portion– tests on anchors and components.

Concrete foundations should be properly sloped to drain so that water pockets do not accumulate with ground material and cause excessive corrosion of the tower's base material.

If steel is exposed to groundwater, special protection is essential. Proper drainage around the steel should be established and periodic inspections conducted. If any steel members are located in severe ground conditions, the thickness will have to be increased by at least 1/16 inches for corrosion allowance.

**Design of Steel Structures (AESC/SEI 48-05)**

Factored Design Loads

Minimum legislated loads are specified according to codes covered by states and local authorities and must meet National Electric Safety Code (NESC). Individual utility companies' planning criteria will usually dictate specific conductor and shield wire sizes. Historical local climates may dictate loads in excess of legislated loads include ice and winds and their combination at specified temperatures. Planning criteria may require measures to prevent cascading failure.

Utility companies need to consider unique loading situations that are applicable to their service area. Tubular frame structure design may need to account for the effects of foundation movement caused by earth movement.

Design Restrictions

Shipping length and weight restrictions are influenced by construction site conditions and material handling limitations. Structure diameter, taper, and deflection restrictions are influenced by the desired appearance of the installed structure. Hot dip galvanized, weathering, painting, and zinc silicate coating are the most commonly used finishes and all influence the exposure, appearance, and regulatory requirements.

Connections and Fasteners

Fasteners are designed as sheer, slip-critical, or sheer-type connections. Typical anchor bolt holes in base plates are 0.375–0.5 inch. Tolerances contained in ASTM Specification A6 should be used as a guide. Commonly used fasteners for pole transmission towers are ASTM A325, A354 A394, A449, and A490 for bolts and A563 for nuts.

**Welded Connections**

Slip Joints

An overlap of 1.42–1.52 times the maximum diameter of the outer section is sufficient to develop the required strength.

**Detailing and Fabrication**

A tower detail drawing consists of erection drawings and bills of materials. Erection drawings show the complete assembly of the structure indicating clearly the position of the members. The owner should coordinate the dimensioning of mating parts obtained from different sources.

Cutting

Any curve or straight edge can be cut with a burning torch. Care must be taken to prevent cracks or other notch defects from forming. Edges prepared for welding should be free from sharp notches. Edges cut with a handheld torch will require grinding to remove notches.

Welding

Welding procedures shall comply with ANSI / AWS D1.1. Workmanship is important for pole structures.

Holes

Holes may be punched or drilled. Care must be taken to maintain accuracy.

Identification

The marks on pieces should be at least 0.50 inches in height.

### Anchor Bolts

The size and length of anchor bolts should be determined by a structural engineer with consideration of the dead and live loads on the transmission line. Threaded reinforced bards are the most common type of anchor bolt and must meet ASTM A615 grade 60 for #5–#18 bars and grade 75 for #11–#18 bars.

## 5.3.6. Construction Project Management

### Scheduling

The use of loaded CPM schedules should be used to present milestone schedules. There should be several schedules for production management. The detail of each schedule should be determined by the level of utilization. Milestone and phase Critical Path Method (CPM) schedules should be prepared for the use of upper-level management and project managers; weekly look-ahead schedules and bar charts should be used by site supervisors.

### Estimating

Estimates should be combined with the schedule as the basis for the cost planning and control of the project. Conceptual estimates can be used to predict the final cost for designing and building projects. On traditional projects, preliminary phase and detailed schedules should be prepared.

### Project Controls

Every project will deviate from its baseline schedule, so the need for a good project controls systems is imperative if the project is to be completed on time and under cost. Project controls are the continuous process of (Mubarak, 2004):

1. Monitoring the progress of work,
2. Comparing the target schedule and cost with the work in progress,
3. Determining any deviations and analyzing for causes, and
4. Making recommendations and taking corrective actions to bring the project back on schedule.

The project controls systems will need to use the information and resources of the estimates and schedule to be able to track the project cost and time. The measurement of work progressed can be determined through various means, such as work-in-place or cost-to-date.

Project controls can evaluate project performance by the use of the following:

- Bar Charts,
- S-Curves (Schedule and Cost ),
- Earn Value Management Systems (EVMS),

**Safety**

The safety record and planning abilities of an EC are two of the most important criteria for selecting preferred contractors in the transmission industry. This is particularly important when using new technology with which a contractor's employees may not have the necessary experience in the process and techniques required for installation. The contractor should be able to prove, with written documentation, a clear and concise safety plan for his on-field activities. There should be a well-kept safety record verifiable over a long period of operation. There should be dedicated safety personnel on site whose roles include, among others:

- Keeping safety manuals and procedures
- Keeping safety records (EMR, DART etc.)
- Staying aware of training requirements of labor,
- Supervising daily job safety and hazard assessments and tailgate meetings, and
- Instituting safety bonuses for field workers when safety targets are achieved.

<u>Safety of Maintenance Personnel (AESC 1997)</u>

The transmission tower must be able to support a vertical load of at least 250 lbs applied independently to all loads without permanent distortion. In most structures, horizontal bracing is required to distribute shear and torsional forces. For structures taller than 200 feet or heavy0end towers horizontal bracing be installed not exceeding 75 feet.

Horizontal bracing is dictated by general stiffness requirements to maintain tower geometry. Factors affecting the type of bracing are the bracing system, face slope, dead load sag of face members, and erection considerations that affect member lengths.

**Quality Assurance and Quality Control (AESC 1997)**

There must be a clear and concise contract between the purchaser and supplier defining the roles and responsibilities of both parties in the purchase, design, detail, testing, fabrication. and delivery of transmission materials.

The purchaser’s QA program outlines the methods, types of inspections, and records necessary to provide production controls.

The QA program defines the personnel that have the responsibility for contract performance, engineering, inspection, and receipt of materials. Contract performance covers enforcement of the terms of the contract relative to payments, delivery commitments, contract changes, and legal matters.

Typical items discussed during the QA-QC review include the acceptance of the supplier's material specifications, sources of supply, material identification, storage, traceability procedures, and acceptance of certified mill test reports.

### 5.3.7. Work Scope of Electrical Contractors

A work scope was developed for EC for HTS cable installation through data acquired from case studies and literature. The work scope was verified with the ELECTRI-NECA task force. The following duties are included in the work scope for EC:

- Foundations,
- Site works,
- Equipment and material selection,
- Connection to renewable energy sources,
- Transmission line design,
- Transmission and distribution lines,
- SCADA installations,
- Installation of poles and lattice structures,
- Connection of energy storage systems to grids and generation sources,
- Existing right-of-way optimization studies,
- Development of transmission material specifications, and
- Installation of measurement and control technologies.

**Table 5.3a. Checklist for Construction Management and Installations (Overall Power System Design and Location, Planning, Zoning, and Environmental Considerations)**

| | Construction Management and Installation (Advanced Superconducting Transmission Cables) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **I. Overall Power System Design** | | | |
| Effect on Overall Power System Design | Power System Design<br>• Low losses due to heat<br>• Achieve increased capacities on existing right of ways and transmission towers without modifications to existing towers.<br>• Low construction and operational costs | Normal | Grid Engineer |
| **II. Location, Planning , Zoning and Environmental Consideration** | | | |
| **Permits and Approvals**<br>• Permitting<br>Environmental enhancement and site Restoration | | High | Owner |
| • Environmental Plans<br>– Noise Control<br>– Erosion and Sedimentation Control<br>– Community Education Plan<br>– Wildlife Impact Assessment and Plans | | | EC |

**Table 5.3b. Checklist for Construction Management and Installations (Product Procurement)**

| | Construction Management and Installation (Advanced Superconducting Transmission Cables) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **III. Product Procurement** | | | |
| Advanced Superconducting Transmission Cables Manufacturers<br>ACCC<br>ACCR<br>HTS | <br><br>Composite Technology Corporation<br>3M Corporation | High | Owner/EC /Product Vendor |
| Access Roads and Transportation on Site<br>• Site Preparation<br>• Erosion Control and Fencing<br>• Grading and Road Improvements<br>• Crane Deployment On Site<br>• Trenching and Cable Laying | | | EC/Subcontractor |

**Table 5.3c. Checklist for Construction Management and Installations (Product Installation)**

| | Construction Management and Installation (Advanced Superconducting Transmission Cables) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **9. Product Installation** | | | |
| Installer /Technician Qualifications | ANSI/NETA ETT | | |
| Installation Code and Standards | Transformers should be installed according to all federal, state, and local regulations<br>• Transmission lines should be installed according to IEEE Standard 524-2003 | High | EC |
| Access Road and Transportation Requirements on Site<br>• Site Preparation<br>• Erosion Control and Fencing<br>• Grading and Road Improvement<br>• Crane Deployment on Site<br>• Trenching and Cable Laying | | Normal | EC/ Subcontractor |
| Equipment for Installation(ACCR and ACCC) | Equipment recommended for installations are (3M 2011):<br>• Bullwheel Tensioners (larger wheel diameters)<br>• Stringing Blocks<br>• Socket Splice<br>• Cable Cutters<br>• Grounding Clamps<br>• Running Grounds<br>• Reel Stands<br>*Chicago grips prohibited on ACCR | High | EC |

**Table 5.3c. Checklist for Construction Management and Installations (Product Installation) (Continued)**

| | **Construction Management and Installation (Advanced Superconducting Transmission Cables)** | **Level of Importance (EC)** | **Responsibility of** |
|---|---|---|---|
| Stringing Procedures | Traditional stringing methods are adopted for HTS cables depending on design and site conditions.<br>• Slack Stringing<br>• Semi Tension<br>• Full Tension<br>• Helicopter<br>3M recommends the use of slack tension stringing for ACCR conductors | High | EC |
| Sagging Procedures | Sagging procedures adopted for ACCR include (3M, 2011):<br>• Line-of-sight measurements<br>• Wave reflection | High | EC |
| Safety | Company safety manuals and procedures well documented<br>• EMR and DART records<br>• Periodic safety training for labor<br>• Daily job safety and hazard assessments and tailgate meetings | | |

**Table 5.3d. Checklist for Construction Management and Installation (Design and Construction of Supporting Components and Construction Project Management)**

| | Construction Management and Installation (Advanced Superconducting Transmission Cables) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **V. Design and Construction of Supporting Components** | | | |
| Foundations | Foundation pad layout should satisfy local and state ordinances<br>Anchor bolts should be accurately aligned | High | EC CM Subcontractor |
| Anchor Materials | Size length must meet ASTM A 36 (ASCE 2008) | High | EC |
| **VI . Construction Project Management** | | | |
| Project Team Qualifications and Availability | Team members and qualifications should be clearly state and presented to owner | High | EC |
| Project Estimate | Attention given to complexity in installation, contract requirements, project duration, commodity price escalation, and market conditions. | High | EC |
| Project Schedule | Provide milestone, phase, monthly, and daily look-ahead schedules | High | EC |
| Project Controls | Bar Charts<br>S Curves<br>Earn Value Analysis | High | EC |
| Quality Assurance Plans | Warranty for work performed encouraged<br>Warranty on all equipment documented | High | EC |
| Safety | Company safety manuals and procedures well documented<br>EMR and DART records<br>Periodic safety training for labor<br>Daily job safety and hazard assessments and tailgate meetings | | |

**Table 5.4. Work Scope of Electrical Contractors for HTS Transmission Cables**

| Work scope of Electrical Contractors for HTS Transmission Cables | | |
|---|---|---|
| **Self-Performed** | **Subcontractors** | **Consultant** |
| **Specialized Equipment Delivery and Installation**<br>• Circuit Breakers<br>• Line Tracker Communication Meter<br>• Phasor Measurement Units<br>• Wide Area Monitoring Systems (WAMS)<br>• SCADA systems<br>• Distribution Monitoring Systems (DMS)<br>• Connection of energy storage systems to grids and generation sources<br>• Existing right-of-way optimization studies<br>• Development of transmission material specifications<br>• Installation of measurement and control technologies. | **Siteworks**<br>• Excavating and Backfilling<br>• Land Reclamation<br>• Stripping and Clearing<br>• Grading<br>• Excavation<br>• Drainage<br>• Dewatering<br>• Fencing<br>• Access Roads<br>• Communication Systems Installations<br>• Erosion and Sedimentation Control<br>**Concreteworks**<br>• Foundations<br>• Piers<br>• Culverts<br>**Environmental Planning**<br>• Land Reclamation<br>• Erosion and Sedimentation Control<br>• Spill Prevention Control and Countermeasure Plans<br>• Community Education Plan<br>• Surveying and Right-of-Way Engineering | **Consultants**<br>• Environmental<br>• Design<br>• Communication Systems and Information Technology<br>• Workforce Training<br>• Surveying and Right-of-Way Engineering<br>• Community Education Plans |

## 5.4. SMART SUBSTATION AND SMART TRANSFORMERS

For the advantages of smart electric grids to be fully realized, transmission and distribution substations will have to be fully automated in order to relay information between generation sources, the distribution network, and the end users of electric power. A substation can be made *smart* by the installation of intelligent electronic devices (IED) in its basic components to enable real-time detection and correction of faults in the grid and communication between the various components of the power grid. For a substation to be considered smart, the following main components will have to be upgraded with intelligent electronic devices (IED) (EPRI 2001, 2003):

- Transformers,
- Circuit Breakers,
- Relaying and Protection Equipment, and
- Optical Measuring Systems.

The owner and their representatives will usually lay out their own requirements for delivering and installing transformers. However, for the EC to be able to take advantage of all the opportunities that are associated with smart grids and to successfully deliver these smart grid projects on time, under cost, and safely, they must be conversant with all the installation and construction management requirements.

**Types of Transformers**

There are two main kinds of transformers depending on the insulation mechanism used. The construction and installation methods used depend on the type of transformer adopted for installation. These two types are

- Dry Transformers, and

- Liquid Insulated Transformers.

Dry transformers are usually installed indoors and need noise insulation. Liquid insulated transformers due to their tendency to catch fire, are usually installed outdoors and need spill containment systems. Based on their location on the power grid, transformers can also be categorized as:

- Power Transformers, or
- Distribution Transformers.

Power transformers transfer power from the generator to a primary transmission and distribution transformers transfer power from a primary transmission to secondary distribution.

### 5.4.1. Impact on Overall Power System Design

The use of high temperature superconducting (HTS) cables means that there will be fewer line losses due to heat. As a result, there will be less need for stepping-up as the power will be able to travel long distances over the line while retaining the required power qualities. Similarly, there will be fewer step-up transformers over the span of a grid.

### 5.4.2. Location, Planning, Zoning and Environmental Considerations

**Permitting**

All permitting requirements must be completed before the respective installation. Consideration should be given the time necessary to secure permits. Permits should be submitted to the right authorities (FERC, State or Local Government).

**Environmental Enhancements and Site Restoration**

If possible, reclamation of the site should be done by planting trees and shrubs around the substation to blend the substation into the existing environment, beautify the surrounding area by hiding the substation from public view, and serve as a noise damper.

**Safety Plans**

A safety plan must be prepared that covers processes to achieve an accident-free construction operation over the duration of the project for all workers, customers and visitors to the site before, during, and after construction has been completed and the project is handed over to owner. A safety audit system must be instituted (Case Study 6, 2011).

**Environmental Plans**

The environmental plans should include the following elements:

<u>Erosion Control and Sedimentation Control</u>

An erosion and sedimentation plan needs to be prepared to lay out a process to preserve topsoil erosion and prevent topsoil runoff into bodies of water.

<u>Noise Control</u>

A noise reduction plan must be prepared if work is to take place near residential areas to prevent noise pollution. All local ordinances should be followed, and the required permits acquired, if work is to be done outside the hours stipulated by the ordinances. All workers should be trained to be sensitive to local resident noise concerns if work is to be done beyond ordinance hours.

Community Education Plan

A community education plan should be prepared to serve as a roadmap for the company's outreach to the community. If the project is near a residential area, the community must be informed about how construction might change traffic patterns, traffic volume, noise level, dust levels, etc. All workers, agents, and subcontractors should be trained to be sensitive to community needs and concerns.

**Spill Prevention Control and Countermeasure (SPCC) Plans**

Under EPA Regulation Title 40 part 112 (EPA 2010), a facility with a total aboveground oil storage capacity greater than 1,320 gallons with a reasonable expectation of discharging oil into or upon navigable waters of the United States or adjoining shorelines must develop a spill prevention and control plan and be governed under the Spill Prevention Act. As such the construction of the substation transformer should be built to conform to EPA safety standards on spill prevention as stipulated in the Control and Countermeasure Plan of the EPA.

Important elements of an SPCC Plan that will affect the work of the EC include (EPA 2010):

- Oil discharge predictions,
- Appropriate secondary containment or diversionary structures,
- Facility drainage,
- Site security,
- Facility inspections,
- Transfer procedures and equipment (including piping),

- Requirements for qualified oil-filled operational equipment,
- Loading/unloading rack requirements and procedures for tank cars and tank trucks, and
- Brittle fracture evaluations for aboveground field constructed containers.

### 5.4.3. Product Procurement

Product procurement includes the following:

Crane Procurement:

Crane procurement must be done with the following considerations and Crane pads should be prepared before cranes are delivered to the site (Lundquist, 2003).

- Size,
- Weight, and
- Sensitivity.

Transformer Procurement:

Transformer procurement requirements are dependent on the complexity and size of the transformer. Major transformer suppliers and manufacturers include (Goulden Report 2010):

- ABB,
- Alscom Corporation,
- Waukesha,
- General Electric, and
- Howard and Cooper.

Lead Time for Ordering Transformers:

The lead time for ordering transformers is dependent on the transformer size, complexity of design, and worldwide demand at the time of order. It can range from a day for some simple low voltage distribution transformers to several months for complex, high-voltage transmission transformers.

Transportation Requirements for Delivery:

The transportation means adopted for delivery of a transformer has a big influence on the cost of delivery, which is affected by insurance, the time of delivery, and future maintenance costs of the transformer. The available transportation methods available for delivery of transformers are (Lundquist et al 2003):

- Truck,
- Railroad,
- Sea Carrier, and
- Air Carrier.

All these forms of transportations have their advantages and disadvantages. The main objectives for the form of transportation chosen should be to reduce the time of delivery and to keep the risk of damage to a minimum.

**Figure 5.28. Truck Transportation (Source: Prolec 2011.)**

The transformer should be protected in a clean, dry environment during transportation and storage before final installation (Brown University FD, 2006; Spang, 2011)

### 5.4.4. Product Installation

**Installer / Technician Qualifications**

There are no nationally recognized smart grid technician certifications. Smart grid technology requires a spectrum of skilled trade certifications for traditional line men and substation installers. The substation wiremen should have at least completed a substation wireman apprenticeship or equivalent training, or should be graduates of electric technician programs from community colleges and technical schools that prepare students for current entry-level work as substation technicians. One existing certification for traditional linemen is the American National Standards Institute and International Electric Training Association (ANSI/NETA ETT) certification.

## Installation Codes and Standards

Agreements, Permits and Certification

Equipment installation must be carried out according to local, state, and national electric codes. Samples of codes used for transformer installation are:

- *NECA 409-2009* National Electrical Installation Standards for Installing and Maintaining Dry Type Transformers (NECA 2009)
- *NECA 410-2005* National Electrical Installation Standards for Installing and Maintaining Liquid-Filled Transformers (NECA 2005)
- *IEEE C57.12.00-2006* IEEE Standard for Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers (IEEE 2006)
- Structure and Foundation – ASCE Substation Structural Design Guide (ASCE 2008)
- NFPA 70 National Electric Codes 2011 (NEC 2011)
- UL Standard 506 – Transformers (UL 2008)
- UL Standard 1561 – K-rated Transformers (UL 2010)
- NEMA ST1 – Specialty Transformers (NEMA 1998)
- NEMA TP-1 – Guide for Determining Energy Efficiency for Dry-Type Transformer (NEMA 2002).

## Access Roads and Transportation Requirements on Site

All access roads to and from the site should be inspected for load and height limitations. The roads to the site should be built or reinforced to hold the loads for trucks and cranes necessary for the installation of all substation components.

Site Preparation

The construction site and all access roads leading to the site should be well prepared to receive all construction loads.

Erosion Control and Fencing

The erosion and sedimentation plan should be implemented and updated to meet site conditions. A protective fence should be constructed around the substation for security purposes and also to meet the requirements of the SPCC. As soon as operationally possible, the site should be secured to protect components from theft and prevent trespassing. The fence must allow easy access to the site for delivery trucks and cranes.

Grading and Road Improvements:

All access roads to and from the substation should be built for easy access for heavy commercial traffic. Existing roads to be used for access to the site should be reinforced to bear large and heavy loads. If temporary access roads are constructed, there should be adequate erosion prevention plans and a reclamation plan in place to reclaim the land after construction is completed. Temporary roads should be able to withstand extreme weather conditions, including rain, sleet, and snow, and must be navigable year round.

**Crane Deployment on Site**

Crane pads should be provided on site as part of site preparation. The crane should be used in the most efficient way by scheduling several activities to be done with limited idle time.

**Trenching and Cable Laying**

Trenches connecting the different components of the substation in the most efficient manner should be planned. Trenching should be done in the most environmentally responsible way and soil must be preserved and protected from erosion and runoff into nearby bodies of water.

**Transformer Oil Spill Containment (EPA 2010)**

With the adoption of smart substations and the influx of high-current AC and DC, transmission substations and their corresponding components will be larger. Oil-filled transformers exceeding 1,320 gallons of oil will require oil containment systems per EPA regulations.

An oil containment system or a bund system will need to be provided for oil-cooled transformers. To be able to satisfy the requirements of an SPCC plan and to meet oil-spill containment standards, the bund system should allow access to the transformer for general maintenance and easy oil change maintenance by vehicles.

The bund wall should be designed to contain 115% of the maximum oil in the transformer in addition to any rain water that might be available. Water control systems should be installed to automatically control the water level within the bund. Sump pumps and water control units should be able to differentiate between water and oil and must not pump out if oil is detected. The bund should be covered to allow people standing on the bund wall access to the transformer.

**Figure 5.29. Transformer Pad Showing Oil Containment System Foundation**
***(Source: Power Engineering LLC 2011)***

**Figure 5.30. Oil Detection Sump Pump**
***(Source: www.skimoil.com 2011)***

**Figure 5.31. Transformer Showing Completed Oil Containment System**
***(Source: Case Study 3)***

The is no requirement to build bunds around existing transformers; nevertheless, transformers installed on or near environmentally sensitive sites with access to water ways and bodies of water may require an oil containment system.

Power cables from the transformer should be designed to exit the bund system in a specially designed duct. The cables should be well sealed to ensure that the bund system is not breached during an oil spill.

**Grounding Substations and Transformers**

Substation grounding is probably the most important safety function performed in the construction of the substation. The grounding must be done with expert care. Below is a photo illustration of the process of grounding a substation.

**Figure 5.32. Joining of Cables to Form a Grid**
***(Source: Case Study 10)***

**Figure 5.33. Cables Welded Together**
***(Source: Case Study 10)***


**Figure 5.34. Grounding Rod Being Driven into Ground**
***(Source: Case Study 10)***

**Figure 5.35. Joining Grounding Rods**
***(Source: Case Study 10)***

**Figure 5.36. Grounding Rod Connection**
*(Source: Case Study 10)*

## Quality Control

Quality Control should cover the following elements (ASCE 2008):

- Visual inspection of the transformer,

- Specific inspection methods for components of the transformers,
- Workmanship fabrication straightness, and
- Dimensional correctness.

**Sound Control**

If a transformer is to be installed indoors, acoustic dampening materials such as fiberglass should be installed on the transformer room walls for indoor transformers. Outdoor transformers should be sited as far away from residential areas as possible. Trees and shrubs should be planted around the substation to reduce noise (Spang, 2010; Brown FD, 2006).

**Inspections**

As part of the post-construction inspection, an inventory list of all the components of the transformer should be made for easy testing and maintenance. All periodic inspections during construction should be adhered to. These inspections should be scheduled on the master schedule so as not to be overlooked. The Commissioning process must be of high priority and must be undertaken according the requirements of the NEC.

### 5.4.5. Design and Construction of Supporting Components

**Foundations**

The foundations for transformers can be either precast or cast in place. The foundation pads should be designed to accept all normal applied and imposed loadings without damage or settlement. Factors affecting the choice of foundation include:

- Geotechnical considerations,

- Foundation loading,
- Base size of structure,
- Rotation and deflection limitations,
- Economics,
- Aesthetics,
- Contractor experience,
- Equipment available,
- Site accessibility, and
- Bund system choice.

The design should also accommodate imposed loading resulting from installation activities. The foundation should be designed to satisfy soil conditions on site. The pad layout should be done accurately and must satisfy all utility, local, and state ordinances. The pad design should be done by a professional engineer. The pad surface should be slightly sloped to prevent water collection at the base of the transformer. The anchor bolts should be accurately aligned.

**Figure 5.37. Transformer Foundation Cast in Place**
*(Source: 4blogspot.com 2011)*

**Figure 5.38. Transformer Pad Foundation Precast**
*(Source: trenwa.com 2011)*

**Anchor Materials**

The size and length of the anchor bolts should be determined by the engineer and all anchor bolts should meet ASTM A 36 / A36M (ASCE 2008).

### 5.4.6. Construction Project Management

**Project Team and Qualifications and Roles**

The project team members and their qualifications will have to be clearly shown with their respective responsibilities clearly stated (Case Study 6, 2011).

**Project Estimate**

The project estimate should be created. Attention should be given to the project's complexity, technological requirements, team requirements, contract requirements, duration of project, and market conditions.

**Project Schedule**

A detailed project schedule should be created as the baseline and maintained throughout the duration of the project. Project schedules should include milestones for the ordering and delivery of transformers and cranes and all testing and inspections. All major milestones should be presented on the schedule. The schedule should include a master overall schedule and have various phase schedules as needed by project crew. Look-ahead schedules should be used for field crews, supervisors, and foremen to recognize project stages.

**Quality Assurance and Quality Control Plans**

A quality assurance (QA) plan must be instituted by the constructor throughout the duration of the project. The quality control and quality assurance programs will depend on the complexity and size of the project. Warranties for workmanship should be stated and backed by the contractors.

**Project Controls**

A project control protocol should be instituted throughout all levels of the company. The company should adopt best practices for project controls so that the controls system is able to identify the exact source, amount contributed by the sources, and party or parties responsible (Syal 2011).

**Safety**

There should be a well-kept safety record that is verifiable over a long period of operation. There should be dedicated safety personnel on site whose roles include (among others):

- Keeping safety manuals and procedures,
- Keeping safety records (Experience Modification Risk(EMR), Days Away, Restricted or Transferred(DART) etc.),
- Keeping informed of the training requirements of labor, and
- Supervising daily job safety and hazard assessments and tailgate meetings.

The CM and installation aspects of smart substations are summarized in Table 5.5.

### 5.4.7. Work Scope for Electrical Contractors

A work scope was developed for electrical contractors (EC) for smart substation and transformer installation. The scope was developed from the CM installation matrix (5.1), which had inputs, from data obtained from literature and case studies. The scope was verified by the ELECTRI –NECA project task force.

The electrical contractor's scope of work in smart substation construction covers the following (Details of opportunities summarized Table 5.2):

- Transformer retrofits,
- Installation of smart transformers,
- Installation of control panels,
- Construction of concrete and pier foundations,
- Substation maintenance,
- Switch gear maintenance and testing,
- Substation grounding,
- Installation of measurement components, and
- Material procurement and management.

**Table 5.5a. Checklist for Construction Management and Installations**
**(Overall Power System Design and Location, Planning, Zoning, and Environmental Consideration)**

| | Construction Management and Installation (Substation and Smart Transformers) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **I.Overall Power System Design** | | | |
| Effect on Overall Power System Design | Power System Design<br>• Number of step up transformers over the grid will be reduced | Low | Designer |
| **I. Location, Planning , Zoning and Environmental Consideration** | | | |
| **Permits and Approvals**<br>• Permitting<br>Environmental enhancement and site restoration<br>• Safety Plans<br>– Safety manuals and procedures<br>– Grounding practices<br>– Daily job hazard assessments<br>• Spill Prevention Control<br>• Environmental Plans<br>– Noise Control<br>– Erosion and Sedimentation Control<br>– Community Education Plan | | High | Owner/EC |

## Table 5.5b. Checklist for Construction Management and Installations (Product Procurement)

| | Construction Management and Installation (Substation and Smart Transformers) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **III. Product Procurement** | | | |
| • Transformer Procurement<br>− Transformer Lead Time<br>− Transportation Requirements for Transformer Delivery | Most common transportation methods:<br>Truck, Railroad, Sea Carrier, and Air Carrier<br><br>Lead time for transformer depends on complexity of design, size, worldwide demand for product, etc.<br><br>Major suppliers: ABB, Alscom, Waukesha and GE and Howard and Cooper | High | Owner/EC /Product Vendor |
| Crane Procurement | | Normal | EC |
| Access Roads and Transportation on Site<br>• Site Preparation<br>• Erosion Control and Fencing<br>• Grading and Road Improvements<br>• Crane Deployment on Site<br>• Trenching and Cable Laying | | Normal | EC/Subcontractor |
| Sound Control | Indoor transformers should have acoustic dampening materials such as fiberglass in the transformer room.<br>Outdoor transformers should be sited as far from residential areas as possible.<br>Trees and shrubs shield the substation as part of environmental enhancement to reduce noise. | Normal | EC |
| Inspections and Commissioning | Performed under NEC requirements | High | EC/Subcontractor |

**Table 5.5c. Checklist for Construction Management and Installations (Product Installation)**

| | **Construction Management and Installation (Substation and Smart Transformers)** | **Level of Importance (EC)** | **Responsibility of** |
|---|---|---|---|
| **IV. Product Installation** | | | |
| Installer /Technician Qualifications | Transformers should be installed according to all federal, state and local codes.<br>• ***ANSI NETA ETT 200***<br>• ***NECA 410-2009*** National Electrical Installation Standards for Installing and Maintaining Liquid-Filled Transformers. , | | EC |
| Installation Code and Standards | • ***NEC Sec 373-11*** National Electric Code Guidelines for Installing Transformers.<br>• ***IEEE C57.12.00-2006*** IEEE Standard for Standard General Requirements for Liquid Immersed Distribution Power<br>• ***UL Standard 506*** – Transformers<br>• ***UL Standard 1561*** – K-rated Transformers<br>• ***NEMA ST1*** – Specialty Transformers<br>• ***NEMA TP-1*** Guide for Determining Energy Efficiency for Dry-Type Transformer | Normal | EC/ Sub-contractor |
| Access Road and Transportation Requirements on Site<br>• Site Preparation<br>• Erosion Control and Fencing<br>• Grading and Road Improvement<br>• Trenching and Cable Laying | Transformer tanks above 1320 gallon require an oil spill system<br>Sump pumps and dewatering systems should differentiate between water and oils during spills<br>Bund should be covered to allow access<br>Power cables should be well sealed to ensure that system is not breached during an oil spill | High | EC |
| Transformer Oil Spill Containments System | Grounding practices should be clearly illustrated and well documented as part of the company safety practices.<br>All project grounding design adhered to and strictly followed | High | EC |
| Quality Control | Company safety manuals and procedures well documented (EMR and DART records)<br>Periodic safety training for labor<br>Daily job safety and hazard assessments and tailgate meetings | | |

**Table 5.5d. Checklist for Construction Management and Installations**
**(Design and Construction of Supporting Components and Construction Project Management)**

| | Construction Management and Installation (Substation and Smart Transformers) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **6. Design and Construction of Supporting Components** | | | |
| Foundations | Foundation pad layout should satisfy local and state ordinances<br>Anchor bolts should be accurately aligned | High | EC CM Subcontractor |
| Anchor Materials | Size length must meet ***ASTM A 36*** (ASCE 2008) | High | EC |
| **VI. Construction Project Management** | | | |
| Project Team Qualifications and Availability | Team members and qualifications should be clearly stated and presented to owner<br>Present lines of communication, roles, and responsibilities of project team | High | EC |
| Project Estimate | Attention given to complexity in installation, contract requirements, project duration and commodity price escalation and market conditions. | High | EC |
| Project Schedule | Provide milestone, phase, monthly, and daily look-ahead schedules | High | EC |
| Project Controls | Bar Charts<br>S Curves<br>Earn Value Analysis | High | EC |
| Quality Assurance Plans | Warranty for work performed encouraged<br>Warranty on all equipment documented | High | EC |
| Safety | Company safety manuals and procedures should be well documented<br>EMR and DART records<br>Periodic safety training for labor<br>Daily job safety and hazard assessments and tailgate meetings | High | EC |

**Table 5.6. Work Scope of Electrical Contractors for Smart Substation and Smart Transformers**

| Work scope of Electrical Contractors for Smart Substations and Smart Transformers | | |
|---|---|---|
| **Self-Performed** | **Subcontractors** | **Consultant** |
| • Substation/Transformer Retrofitting<br>• Installing HTS Transformers<br>• Installing Measurements Components<br>• Spill Prevention Control and Countermeasure Plans<br>• Consulting and Training<br>• Project Management<br>• Specifications Development<br><br>**Specialized Equipment Delivery and Installation**<br>• Circuit Breakers<br>• HTS Transformers<br>• Line Tracker Community Meter<br>• Phasor Measurement Units<br>• Wide Area Monitoring Systems (WAMS)<br>• Substation Automation Sensors<br>• SCADA systems<br>• Distribution Monitoring Systems (DMS)<br>• Supplier Evaluation and Analysis | **Site Works**<br>• Excavating and Backfilling<br>• Land Reclamation<br>• Stripping and Clearing<br>• Grading<br>• Excavation<br>• Drainage<br>• Dewatering<br>• Fencing<br>• Access Roads<br>• Installing HTS Transformers<br>• Communication Systems Installations<br>• Erosion and Sedimentation Control<br><br>**Concreteworks**<br>• Foundations<br>• Piers<br>• Culverts<br><br>**Environmental Planning**<br>• Land Reclamation<br>• Erosion and Sedimentation Control<br>• Spill Prevention Control and Countermeasure Plans<br>• Community Education Plan<br>• Surveying and Right of Way Engineering | **Consultants**<br>• Environmental<br>• Design<br>• Communication Systems and Information Technology<br>• Workforce Training<br>• Surveying and Right of Way Engineering<br>• Community Education Plans<br>• Consulting and Training |

## 5.5. AUTOMATED/ADVANCED METERING INFRASTRUCTURE (AMI)

An automated/advanced metering infrastructure (AMI) is an integration of several technologies. It consists of four main components: a smart meter at the customer's location, a communications network between the utility company and the smart meter, the home area network, and the data management software installed by the utility company to track and control the communication and electric flow and serve as interconnection to automated utility billing between the utility company and the consumer (EPRI 2007, Hart 2008). However, more technologies can be built into the systems, such GIS and data management applications (Case Study 7, 2011).

An AMI enables utility companies to undertake demand response at the customer level by giving consumers the ability to make informed decisions (NETL 2008). The home area network gateway reads and links the meter to various end use devices and communicates with the service provider.  Installation of an AMI can be considered under the following:

- The installation and retrofitting of electric smart meters,
- Installation of sensing, measurement, and advanced components on the distribution network, and
- The development, installation, and implementation of a data management system or a SCADA system.

**Smart Meters**

The installation and retrofitting of smart meters is one of the most important aspects of deploying smart technology, as it is the main interaction between the utility company and the consumer. Due to this sensitivity to customer opinions and acceptance, the planning for smart meter installation and retrofitting is the most critical part of any smart grid technology adaptation.

### 5.5.1. Overall Power System Design

NA

### 5.5.2. Location, Planning, Zoning, and Environmental Considerations

NA

### 5.5.3. Product Procurement

Utility companies procure smart meters under three main methods (Case Study 7, 2011):

- In-house procurement and deployment,
- Outsourcing to vendors and subcontractors, and
- A hybrid solution between the two systems.

The decision to either outsource the procurement and/or the installations of smart meters by a utility company is determined by several factors including the existence of an in-house installation capability or expertise in the company. When the procurement and installation of smart meters are outsourced to vendors or manufacturers, these manufacturers in turn sublet the installation of the meters to subcontractors. The vendors are usually supervised by the project management department of the utility company.

**Smart Meter Standards**

Smart meter installation is regulated under the *ANSI C12* (ANSI 2008), which describes the protocol for meters that employ the use of two-way communications in the American market.

### 5.5.4. Product Installation

The installation of smart meters is of importance to utility companies, as is the gateway to the HAN. The smart meter is also the first point of contact between the utility company and the consumer. Those who install the smart meters are indirectly the representatives of the company, and must exhibit all the professionalism that would be exhibited by an employee of the utility company.

Problems can be reduced or avoided with critical planning for smart meter installations. Smart meter installations and wireless communication stations can be planned with the use of GIS and GPS for more efficient installation and tracking. Route optimization software can be combined with scheduling software for an efficient deployment. The smart meter installation process is illustrated in Figures 5.12 – 5.14.

**Figure 5.39. Image Installing a Smart Meter**
*(Source: Pepco 2011)*

Easily accessible programs such as Google Earth can be used to ensure the accurate siting and location of the poles and towers on which wireless communication systems will be installed to ensure the most effective coverage. These programs can also be used for the efficient planning of smart meter installations.

### Cell Relays

The installation of cell relays on poles and at communication centers requires specialized electrical installation knowledge. This is either done by the line workers of utility companies or can be outsourced to electrical contractors who can prove they understand the philosophy and workings of a utility company, and can install these components at a lower cost than their competitors (Case Study 7, 2011).

Cell relays are installed on poles at determined intervals to monitor and transfer data from the grid to a control center. The specific communication technology adopted will be determined by the utility company, and this will determine the installation processes to be used.

### Installer / Technician Qualifications

No qualifications are needed for installing smart meters. However, for one to be able to install cell relays and other complicated electrical components, one needs to be a qualified electrician in the state of operation.

### Installation Codes and Standards

ANSI C12 (ANSI 2008)

## 5.5.5. Construction Project Management

Free software such as Google Earth or more complicated GIS programs can be used to identify and site cell towers on which cell relays will be installed and used to find the most efficient ways of deploying smart meters at homes and commercial premises (Case Study 14, 2011).

**Scheduling**

Scheduling for the installation of smart meters can be a very important tool to the EC as it can aid in reporting work progress to the utility company and electrical contractor. Scheduling optimization software will ensure that field technicians with the right skills are dispatched to install the smart meters and cell relays with little disruption to customer power supplies (Morris, 2011). The use of scheduling software like Primavera and M S Projects can be used in combination with GIS.


**Figure 5.40. Using Google Earth to Plan Siting of GSM Relay Tower Points (Source Google Earth)**

For the EC to add value as an installer of AMI technologies, they need to operate like an agent of the utility company and adopt the standards of the utility company in dealing with customers. Scheduling tools should be able to take advantage of real-time, unscheduled events and should also be capable of rerouting and rescheduling technicians when the need arises. In other words, the installer needs to be efficient in responding to the needs and problems of consumers (Morris, 2011).

**Figure 5.41. Scheduling Planning Using Google Earth**

## Inspections

There must be a well-planned and implemented periodic supervisory check on installed meters using statistically random methods. All periodic inspections during installation should be carried out to ensure quality installation and customer satisfaction.

**Installation of Smart Components on the Distribution Network**

The EC will have to stay abreast of current measurement technologies on the distribution grid to be able to install, monitor, maintain, and deploy such technologies in the most efficient way possible. Some of the measurement technologies that might be needed will include measurement components like line RF temperature, current sensors, relay cells, and line-tracking communicating meters.

### 5.5.6. Work Scope of Electrical Contractors

A work scope was developed for the EC for AMI installations. The work scope was developed from case study visits and literature reviewed. The work scope was verified by the case study participants and by the NECA-ELECTRI taskforce. The work scope of EC includes the following duties:

- Installing SCADA systems,
- Installing cell relays,
- Installing smart meters,
- Installing measurement technologies, and
- Installing cell /communication towers.

**Table 5.7a. Checklist for Construction Management and Installations**
**(Overall Power System Design and Location, Planning, Zoning Environmental Considerations, and Product Procurement)**

| | **Construction Management and Installation (AMI)** | **Level of Importance (EC)** | **Responsibility of** |
|---|---|---|---|
| **I. Overall Power System Design** | | | |
| NA | NA | NA | NA |
| **II.Location, Planning , Zoning and Environmental Consideration** | | | |
| NA | NA | NA | NA |
| **III. Product Procurement** | | | |
| AMI Delivery Methods (Utilities) | Delivery methods used for AMI installations:<br>• Utility Procurement and Deployment<br>• Vendor Procurement and Deployment<br>• Utility Procurement and Contractor Deployment | High | EC /Subcontractor /Supplier |
| Top Five US Smart Meter Manufacturers (Berst, 2010) | Itron, Landis Gyr, Sensus, Elster, and General Electric | | |
| Smart Meter Standards (ANSI 2008) | ANSI C12 (ANSI 2008) | | |
| Communication Technologies (Refer to Chapter 4 ) | Broadband Over Power Line<br>Wireless<br>Miscellaneous | | |

**Table 5.7b . Checklist for Construction Management and Installations**
**(Product Installation, Design and Construction of Supporting Components, and Construction Project Management)**

| | Construction Management and Installation (AMI) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **IV. Product Installation** | | | |
| Installer /Technician Qualifications Smart Meters Cell Relays | No qualifications for installing smart meters<br><br>ANSI /NETA ETT 2000 | | |
| Installation Code and Standards | • ANSI C12<br>• NFPA 70 National Electric Codes 2011 | | EC/Subcontractor |
| Quality Control | Specific inspection methods for components of the transformer<br>Workmanship checks | High | EC |
| **V . Design and Construction of Supporting Components** | | | |
| NA | NA | NA | NA |
| **VI. Construction Project Management** | | | |
| Project Team Qualifications and Availability | Team members and qualifications should be clearly stated and presented to owner as part of project bids. | High | EC |
| Project Estimate | Attention given to complexity in installation, contract requirements, project duration, commodity price escalation, and market conditions. | High | EC |
| Project Schedule | Provide milestone, phase, monthly, and daily look-ahead schedules to owners, PM, supervisors, etc. | High | EC |
| Project Controls | Bar Charts<br>S Curves<br>Earn Value Analysis | High | EC |
| Quality Assurance Plans | Warranty for work performed encouraged<br>Warranty on all equipment documented | High | EC |
| Safety | Company safety manuals and procedures well documented<br>EMR and DART records<br>Periodic safety training for labor | High | EC |

**Table 5.8. Work Scope of Electrical Contractors for AMI**

| Work scope of Electrical Contractors for AMI | | |
|---|---|---|
| **Self-Performed** | **Subcontractors** | **Consultant** |
| • Cell Relays and Switches Installation<br>• Smart Meters Installation<br>• Communication Technologies Installation<br>• Integration of DMS and AMI<br>• Specification Development<br>• Evaluation and Selection of Vendors<br>• Installation of Communication Technologies<br>• Monitoring and Analysis of AMI Systems<br>• Design of AMI | • Smart Meters Installation | • SCADA Design and Installations |

## 5.6. THE HOME AREA NETWORK

The home area network (HAN) provides secure communication between the AMI network and the consumer. A HAN might include the installation of a residential renewable energy generating source, a home charging battery to store excess generated energy, an inverter, a home gateway, a programmable communicating thermostat (smart thermostat), smart appliances, a personal home electric vehicle (PHEV) charging station, and automated lighting controls. All of these connect to each other through a communication technology like Zigbee or WiFi. Home area networks can be used by both residential and commercial customers for cost savings on power usage.

The smart meter installed by the utility company outside the home is the link between the utility company's AMI system and the HAN. The consumer will have to acquire smart devices to be able to fully benefit from the communications capabilities of the AMI and smart meter.

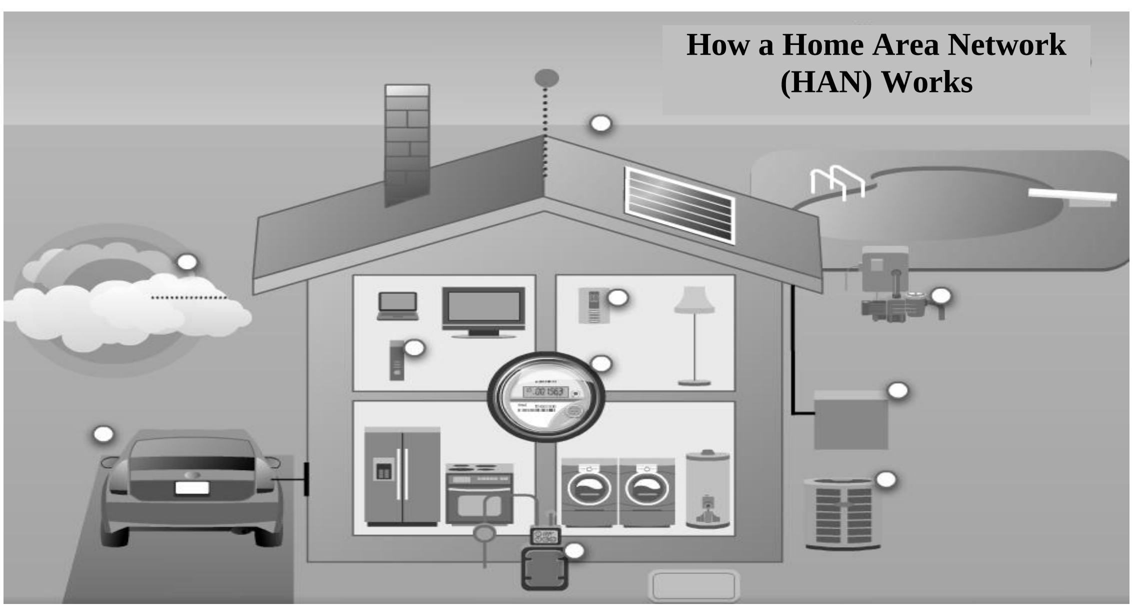



**Figure 5.42. Home Area Network**
*(Source: sdge 2011)*

**Communication Technologies**

There are several technologies, both wired and wireless, for home automation. Some of these technologies are also proprietary, such as Zigbee and Z-Wave (Sharma, 2008). Zigbee, which is an ultra-low-power wireless networking processor, has emerged as the technology of choice for many vendors of home automation equipment. Zigbee is a built on the IEEE 802.15.4 wireless standards and this enables widespread operability between several technologies while offering security and providing real-time, two-way communication between an AMI and HAN (Sharma, 2008). This is due to the low cost, self-healing capabilities and flexibility with several types of equipment. The Zigbee processor is being installed in home equipment elements from security systems and lighting controls to audio/video systems and smoke alarms.


**Figure 5.43. EM 260 Zigbee Processor**
*(Source: Sharma 2008)*


**Figure 5.44. Home Gateway**
*( Source: Energyhub(2011)*


**Figure 5.45. Programmable Communicating Thermostat**
*(Source: Designboom 2011)*

### 5.6.1. Impact on Overall Power System Design

A fully operational HAN will enable two-way communication between the consumer and the utility company. This enables the utility company to have a more efficient planning protocol for its distribution assets. This will reduce operational costs by eliminating redundant generation and substation assets (Case Study 16, 2011).

### 5.6.2. Location, Planning, Zoning, and Environmental Considerations

There are no special permitting requirements for installing smart equipment like appliances in the home beyond the safety requirements stipulated in the National Electrical Codes. However, there are permitting requirements for installing solar panels and micro wind turbines on homes or on commercial buildings. Some states are exploring the integration of residential renewable generation sources to the grid for net metering purposes and are amending their building codes to accommodate the increasing interest in the installation of charging stations in homes.

### 5.6.3. Product Procurement

Several companies are combining technologies such as Zigbee, WiFi, and cellular wireless technologies to come up with centrally controlled home area applications for homes and commercial buildings. Companies are continually partnering with electrical companies to serve as vendors and installers for their technologies. Several companies have developed stand-alone systems that control all the home area technologies from a single source.

### 5.6.4. Product Installation

**Installation Standards**

To install a photovoltaic (PV) system, local building codes, zoning ordinances, and subdivision covenants must be followed. This is mostly governed at the local level (USDOE 2009). The authority with jurisdiction, usually the building department of a city or state, must have codes that comply with the National Electric Code (National Fire Protection Association 70) with regard to all electrical work on homes and businesses. Article 690 of the NEC specifically applies to the installation of photovoltaic systems (Chiras et al., 2009). Article 690 has been in the National Electric Code since 1984 (IAEI 1999).

There are no new standards for installing most of the components of a HAN besides the typical qualifications for electricians as determined by the state of operation. For solar installations, however, there are upcoming qualifications for installers from the North American Board of Certified Energy Practitioners (NABCEP) and the Interstate

Renewable Energy Council (IREC) Institute for Sustainable Power Quality (ISPQ) retraining certifications.

Due to the complexity of PV systems, DOE recommends customers seriously consider having a professional solar contractor install the system (DOE 2009). Experience in installing grid-connected systems is especially useful due to the extra installation steps such as interconnection with the grid. The contractor should have an electrical contractor's license. Certain solar rebate programs may also require specific certification (DOE 2009).

Contracting for commercial solar installations for buildings is a more complex process. The installation of solar arrays will usually be contracted using one of the existing delivery systems. This will usually involve several project participants such as designers, rack manufacturers and installers, and inverter vendors and installers, for example.

Solar

The main components of a residential solar installation are mounting structures, power conditioners, and an on-site energy storage device.

Inverters

An inverter converts the generated DC into AC and synchronizes with the electricity in the grid (Solar Direct 2010). Inverters are used in conjunction with charge controllers to protect the battery from overcharging (USDOE 2010).

**Figure 5.46. Inverter (left) and Charge Controller (right)**
*(Source: EERE 2011)*

Electricity Storage

The electricity storage, or the batteries, is where PV cells store excess energy. These batteries can be tapped for electricity when the PV cells do not provide a sufficient amount of energy (i.e. on a cloudy day). Battery banks are expensive and lower the overall efficiency of the PV system; only about 80% of the energy that goes in can be reclaimed (USDOE 2008). Regardless, batteries are a way to store excess PV energy, and are a necessity for off-the-grid PV systems.

### 5.6.5. Design and Construction of Supporting Components

There are four types of mounting structures: roof/ground, top of pole, side of pole, and tracking mounts (AltE University 2010). The first three types are fixed; this means the solar panels are fixed in a position according to the latitude and longitude of the location that receives the maximum amount of sunlight.

Rack mounts can be used on the ground or on flat or sloped roofs. Racks are primarily made out of aluminum and consist of three main parts: the anchors that keep the rack attached to the surface, the legs that provide the tilt of the panels, and the horizontal bars to which the PV modules are attached. Rack mounts are relatively easy to install. If the surface is the ground, te legs of the rack must be firmly anchored into a foundation, usually concrete piers or pilings set in the ground.

The mounting structures should be strong enough to bear the weight of the PV arrays in all prevailing weather conditions. Before arrays are installed on roofs, the roofs should be inspected to ensure they can withstand the additional weight of the arrays and the mounting structure.

Rack mounts can also be installed on a roof. Metal L-footings and lag screws are used to attach the mount to the roof.

**Figure 5.47. L-Footings Bolted to a 2x4 Block Attached to Adjacent Roof Rafters**
*(Source: Chiras et al., 2009)*

Silicon caulk should be applied around the footing and screws to prevent rain or snow from penetrating the roof.

### 5.6.6. Construction Project Management

Refer to Table 5.9.

### 5.6.7 Work Scope of Electrical Contractors

A work scope was developed for EC for ESD. This work scope was developed from literature and verified by the ELECTRI-NECA task force. The work scope for ESD includes the delivery and installation of:

- Load Control Receivers,
- Automated Lighting and Controls,
- Roof Solar Installations,
- Home Batteries,
- Micro Wind Turbines,
- PHEV Charging Points,
- Communication Technologies, and
- Smart Appliances.

**Table 5.9a. Checklist for Construction Management and Installations (Overall Power System Design, Location, Planning, Zoning, Environmental Considerations, and Product Procurement)**

| | **Construction Management and Installation of Home Area Network (HAN)** | **Level of Importance (EC)** | **Responsibility of** |
|---|---|---|---|
| **I. Overall Power System Design** | | | |
| Effect on Overall Power System Design | • Enables two-way communication between the consumer and the utility company. | Low | |
| **II. Location, Planning , Zoning and Environmental Consideration** | | | |
| Permits and Approvals | Building Codes<br>National Electric Codes(National Fire Protection Association 70) | High | Owner/EC |
| **III. Product Procurement** | | | |
| Commercially Available Components<br>Home Area Networks | Home Gateway<br>Programmable Communicating Thermostat (Smart Thermostat)<br>Automated Light Controls | High | Owner/EC<br>/Product Vendor |
| Inspections and Commissioning | Performed under NEC requirements | High | EC/Subcontractor |

**Table 5.9b. Checklist for Construction Management and Installations (Product Installation)**

| | Construction Management and Installation Home Area Network (HAN) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **IV. Product Installation** | | | |
| Installer/Technician Qualifications | • National American Board of Certified Energy Practitioners (NABCEP)<br>• Interstate Renewable Energy Council (IREC) Institute for Sustainable Power Quality (ISPQ) Training/Retraining Certification | | |
| Installation Code and Standards | • Building Codes<br>• National Electric Codes Section 90<br>• Photovoltaic Power Systems and National Electric Code: Suggested Practices. SANDIA Report SAND 96-2797 (SANDIA 1996) | | EC |
| Quality Control | Visual inspection of all components delivered to site<br>Specific inspection methods for components of the HAN<br>Strict adherence to manufacturers recommended installation processes | High | EC |

**Table 5.9c. Checklist for Construction Management and Installations**
**(Design and Construction Supporting Components and Construction Project Management)**

| | Construction Management and Installation Home Area Network (HAN) | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **V. Design and Construction of Supporting Components** | | | |
| Mounting Structures | Racks should be securely secure to roof.<br>Racks installed on the ground should be securely installed into a foundation.<br>Racks should be inspected before cells are installed<br>Silicon caulk should be applied around all footings and screws adjoining the roof. | High | EC/ CM Subcontractor |
| **VI. Construction Project Management** | | | |
| Project Team Qualifications and Availability | Team members and qualifications should be clearly stated and presented to owner | High | EC |
| Project Estimates | Attention given to complexity of installation, contract requirements, project duration, commodity price escalation, and market conditions, especially steel and aluminum for racks. | High | EC |
| Project Schedule | Provide milestone, phase, monthly, and daily look-ahead schedules | High | EC |
| Project Controls | Bar Charts<br>S Curves<br>Earn Value Analysis | High | EC |
| Quality Assurance Plans | Warranty for work performed encouraged<br>Warranty on all equipment documented | High | EC |
| Safety | Company safety manuals and procedures well documented<br>EMR and DART records<br>Periodic safety training for labor<br>Daily job safety and hazard assessments and tailgate meetings (Commercial Installations) | | |

**Table 5.10. Checklist Work scope of Electrical Contractors Home Area Network (HAN)**

<table>
<tr><th colspan="3">Work scope of Electrical Contractors Home Area Network (HAN)</th></tr>
<tr><th>Self-Performed</th><th>Subcontractors</th><th>Consultant</th></tr>
<tr><td>Delivery and Installation of :<br>• Load Control Receivers<br>• Automated Lighting and Controls<br>• Roof Solar Installations<br>• Home Batteries<br>• Micro Wind Turbines<br>• PHEV Charging Points<br>• Communication Technologies<br>• Smart Appliances</td><td></td><td>Consultants<br>• Home Energy Audits<br>• Design of Solar Installations</td></tr>
</table>

## 5.7. MISCELLANEOUS TECHNOLOGY: PLUG-IN ELECTRIC VEHICLE CHARGING STATIONS

According to Becker and Sidhu (2009), plug-in hybrid and plug-in electric vehicles will constitute 64% of light vehicle sales and 24% of light vehicle fleets in the U.S. by 2030. This will make the servicing of these vehicles imperative. The provision of smart charging stations will be one of the biggest changes in the coming years. Charging stations can be separated into the public commercial charging and home charging stations. In America, unlike other parts of the world, it is estimated that home charging outlets will constitute the majority of charge stations by 2015 (Pike Research 2010). However, there will be a corresponding demand for commercial charging stations as home charging station demand increases.

Home charging stations are considered as level 1and level 2 stations and are divided into two kinds, mainly for overnight charging in individual homes and overnight charging in apartment complexes (Morrow et al., 2008). Commercial charging stations are considered as level 2 and level 3 with emphasis on fast and safe charging for commuters.

### 5.7.1 Impact on Overall Power System Design

Charging stations do not yet have the volume to have any effect on the grid as a whole. However, if the rate of construction continues to increase and there are several charging stations on the grid, then this will affect the way electricity is used. For example, if there are many cars parked and getting charged on the grid overnight, then the rates from the utility companies might have to increase due to the load demands from storage batteries. There will be the opportunity to use vehicle to grid (V2G) power for grid support. This is where stored power in car batteries will be tapped to augment grid power in the event of power shortfalls or grid quality issues.

### 5.7.2 Location, Zoning, and Environmental considerations

**Residential Charging**

When siting a charging station for a residential garage, irrespective of the charging level employed, the main issues considered are (Morrow et al 2008):

- Where does the vehicle typically park?
- Where is the charge inlet located on the vehicle? and
- What is the length of electric vehicle's charge cord?

The charging station location should balance the requirements of safety, relative ease to power source, and the ventilation requirements of NEC Article 625.

**Figure 5.48. Typical Level 2 garage charging station (gm-volt.com)**
*(Source: Morrow et al 2008)*

### Commercial Charging

For apartment complexes, siting consideration is given to parking locations. Typically, there are distribution points at each complex for distribution to individual apartments. Usually circuit protection will have to be installed to protect the charging units because the fuse panels are usually installed in the apartments (Morrow et al., 2008).

**Figure 5.49 – Distribution Point of an Apartment Complex**
*(Source:Morrow et al 2008)*

### Commercial Charging Stations

Commercial facilities typically have a single utility service entrance, with power distributed to several subpanels throughout the building.  New meters and accounts will need to be established with the power company to service only the charging station. However, when this approach is taken, the cost should be charged to the customer as part of the contract. The location of a charging station should be easily accessible and easy to find (Morrow et al., 2008).

### 5.7.3. Product Procurement

The main vendors and installers of PHEV stations according to Morris et al (2011) are:

- Ecotality,
- Clipper Creek,
- Aeroveironment,
- Coulomb,
- General Electric,
- Pep Stations,
- Better Place, and
- Leviton.

### 5.7.4. Product Installations (Morrow et al., 2008)

**Installation Standards**

Several jurisdictions are developing installation standards for electric vehicle charging stations. Existing installation standards are:

- UL 2202, the Standard for Safety of Electric Vehicle (EV) Charging System Equipment (UL 2009).
- National Electric Codes (NEC) Section 625 (NEC 2011).

**Charging Garages**

Residential charging outlets consist of a dedicated standard 15–20 Amp breaker on a 120V circuit with a ground fault interrupter for a level 1 charger or a dedicated 40 Amp or higher rated 240V circuit for a level 2. For commercial stations, only level 2 and level 3 stations require a dedicated 60 Amp or higher 480V circuit with special grounding equipment (Morrow et al., 2008). There must be coordination with utility companies to establish dedicated meters for commercial installations

**Accessibility**

Commercial charging stations are required under the Americans with Disabilities Act to provide accessible parking spots for disabled patrons. This spot must be provided solely for the use of persons with disabilities and must be appropriately labeled with the recommended signage.

**Lighting and Shelter**

For commercial charging stations, lighting is recommended for convenience and safety. This especially needed in isolated charging stations.

**Signage**

There should be signs directing drivers to the charging station stalls and signs indicating that the parking spaces are exclusively for charging.

### 5.7.5. Design and Construction of Supporting Components

**NA**

### 5.7.6. Construction Project Management

**NA**

### 5.7.7. Works Scope of Electrical Contractors

A work scope was developed for EC for installing PHEV charging stations. This work scope was developed from literature and verified by the ELECTRI-NECA task force. The work scope for ESD includes the delivery and installation of the following:

- Installation of Charging Stations (Residential and Commercial)
- Design and Building of Commercial Charging Lots
- Material Procurement
- Construction Management
- Specification Development
- Vendor Evaluations and Selection

**Table 5.11a. Checklist for Construction Management and Installations (Overall Power System, Design, Location, Planning, Zoning, Environmental Considerations, and Product Procurement)**

| | Construction Management and Installation PHEV Charging Stations | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **Overall Power System Design** | | | |
| Effect on Overall Power System Design | • Vehicle-to Grid-Capabilities | Low | |
| **II. Location, Planning , Zoning and Environmental Consideration** | | | |
| Siting Considerations | Where car regularly parks<br>Location of charge outlet on car<br>Length of charging cords<br>Ventilation requirements<br>Safety<br>Location to distribution boxes | High | Owner/EC |
| **II. Product Procurement** | | | |
| Vendors and Installations | U.S. Market Leaders (Morrow et al., 2008):<br>• Ecotality<br>• Clipper Creek<br>• Aeroveironment<br>• Coulomb<br>• General Electric<br>• Pep Stations<br>• Better Place<br>• Leviton | High | Owner/EC/Product Vendor |

**Table 5.11b. Checklist for Construction Management and Installations (Product Installation)**

| | Construction Management and Installation PHEV Charging Stations | Level of Importance (EC) | Responsibility of |
|---|---|---|---|
| **IV. Product Installation** | | | |
| Installer/Technician Qualifications | • Qualified Electricians | | |
| Installation Code and Standards | • UL 2202, The Standard for Safety of Electric Vehicle(EV) Charging System Equipment (UL 2009)<br>• National Electric Codes Section 625 (NEC 2011) | | EC |
| Charging Garages | Dedicated outlets with circuit breakers (15–20 Amp on 120V level 1 and 40 Amp on 240V for level 2, 60 Amp 480 circuit for level 3) | Normal | EC/ Subcontractor |
| Grounding | Grounding practices should be clearly illustrated and well documented as part of the company safety practices.<br>All project grounding design adhered to and strictly followed as stipulated by manufacturers and NEC | High | EC |
| Accessibility | Charging spots for those with disabilities should be provided for commercial charging stations under the American with Disabilities Act (ADA) | High | EC |
| Lighting, Shelter, and Signage | Adequate lighting and signage should be provided for commercial installations. | High | EC |

**Table 5.11c. Checklist for Construction Management and Installations (Design and Construction of Supporting Components and Construction Project management)**

| | Construction Management and Installation PHEV Charging Stations | Level of Importance(EC) | Responsibility of |
|---|---|---|---|
| **V. Design and Construction of Supporting Components** | | | |
| NA | NA | NA | NA |
| **VI . Construction Project Management** | | | |
| Project Team Qualifications and Availability | Team members and qualifications should be clearly stated and presented to owner | High | EC |
| Project Estimate | Attention given to complexity in installation, contract requirements, project duration | High | EC |
| Project Schedule | Provide milestone, phase, monthly, and daily look-ahead schedules | High | EC |
| Project Controls | Bar Charts<br>S Curves<br>Earn Value Analysis | High | EC |
| Quality Assurance Plans | Warranty for work performed encouraged<br>Warranty on all equipment documented | High | EC |
| Safety | Company safety manuals and procedures well documented<br>EMR and DART records<br>Periodic safety training for labor<br>Daily job safety and hazard assessments and tailgate meetings | | |

**Table 5.12. Work Scope of Miscellaneous Technology**

| Work scope of Electrical for Miscellaneous Technology | | |
|---|---|---|
| **Self-Performed** | **Subcontractors** | **Consultant** |
| Installation of Charging Stations (Residential and Commercial)<br><br>Design and Building of Commercial Charging Lots<br><br>Material Procurement<br><br>Construction Management<br><br>Specification Development<br><br>Vendor Evaluations and Selection | | Consultants |

## 5.8. SUMMARY

This chapter explored the installation and construction management (CM) aspects of the five smart grid related technologies identified. The technologies considered were smart substation and smart transformers, automated metering infrastructure (AMI), advanced superconducting transmission cables, energy storage devices, and home area networks. The CM aspects for the respective technologies were considered under the categories of impact on the overall power system design; location, planning, zoning, and environmental considerations; product procurement; product installation; design and construction of supporting components; and construction project management.

Based on the previously mentioned technologies and the categorizations, a matrix was compiled for each technology and the work scope of electrical contractors was compiled.

# CHAPTER 6

# SUMMARY AND CONCLUSIONS

## 6.1. OVERVIEW

This research analyzed and explained the installation and construction management aspects of smart grids, with a focus on electrical contractors. To enhance the understanding of these construction management and installation aspects, major smart grid initiatives undertaken by stakeholders were identified. Smart grid technologies, existing and emerging, were categorized into five main categories. Five technologies were selected, and the construction management and installation aspects, as well as the work scope relating to electrical contractors, were developed. These technologies were chosen following informal discussions with members of the ELECTRI-NECA task force and its case study respondents.

The research need, goal, objectives and key work steps, as well as the scope and overall limitations, were presented in chapter one. Chapter two presented a summary of the relevant literature. Chapter three presented major initiatives by stakeholders. Chapter four presented smart grid technologies, emerging and existing. Chapter five outlined the construction management and installation requirements that have been developed for the five technologies selected by the researcher.

This chapter summarizes the overall research output. It is followed by the research conclusion and, finally, potential areas for future research.

## 6.2. SUMMARY OF OBJECTIVES ACHIEVED

The goal of this research was to understand the installation and construction management aspects of smart grid installations. This section summarizes the work performed to achieve the research objectives,

### 6.2.1 Objective 1: Investigate major smart grid initiatives by major stakeholders.

The work performed in achieving objective 1 was divided into three work steps. These are presented in chapter 3. All current and upcoming initiatives undertaken by the government, investors and the power generation and distribution sector were compiled.

These initiatives were compiled from the information available in government documents, and in government and utility company websites. These ventures helped project future developments and forecasts for smart electric power grids. The main stakeholders covered in the literature review were:

- Government ( federal, state and local): regulatory and investment initiatives
- Industry (utilities, generation and transmission companies, appliance manufacturers, and information technology companies)
- Trade Groups and Associations (e.g. National Electrical Contractors Association)

Major initiatives were analyzed for their impact on the growth of the smart grid movement and, subsequently, on the electrical contracting industry.

These projects were also analyzed for their current and future impacts on the electrical construction industry, in terms of regulations and demand for smart grid installations. The programs identified, together with their impacts, were presented to the industry task force for input and feedback. These work steps mark the completion of the first objective.

### 6.2.2. Objective 2: Identify and describe the various existing and emerging "smart" technologies.

Smart grid technologies were identified from the various initiatives described in objective #1, together with the literature and case studies. These technologies were organized under the following 5 categories, using the classifications by NETL (2007) and Roncero 2008:

- Advanced Components
- Sensing and Measurement
- Advanced Control Methods
- Integrated Communications
- Improved Interfaces and Decision Support

The technologies under the various designations were described, together with their location on the grid, deployment status and existing installations.

Case study interviews were conducted with two major utilities, a national transmission company, and electrical contractor, a post-doctoral fellow researcher in electrical grids, a director in charge of smart grid for a public utilities commission for information about the technologies being investigated in this research. The literature from various appliance manufacturers, smart technology manufacturers and suppliers, and other industry sectors, was also reviewed. Case studies were analyzed for the five major technologies selected by the author, in consultation with industry experts. The outputs, which are presented in chapter 4, were presented to the industry task force for input and feedback.

### 6.2.3. Objective 3: Analyze and determine the installation and construction management aspects of the smart technologies described in objective #2 and develop a checklist of potential opportunities for the electrical construction industry.

Installation and construction management (CM) aspects for the technologies from objective #2 were established using data acquired from electrical installations and construction management literature. Construction management and installation aspects related to electrical contractors were developed using case study observations, data from informal interviews and the literature.

The installation aspects were categorized as follows, based on the construction work stages:

1. Overall Power System Design
2. Location, Planning, Zoning and Environmental Considerations
3. Product Procurement
4. Product Installation
5. Design and Construction of Supporting Components
6. Construction Project Management

From the reviewed literature, industry interviews and case study projects, a work scope matrix was designed for electrical contractors, by breaking down all of the likely work processes to be undertaken into categories, according to responsibility for completing the task. The work was broken down into tasks to be performed by electrical contractors, tasks be given out as subcontracts, and miscellaneous tasks, which covered undefined tasks and tasks outsourced to consultants.

A matrix was developed to determine the opportunities for electrical contractors, using the work processes data obtained from case studies and the literature. The matrix was categorized in the following way:

- Installation aspects
- Electrical contractor-related issues
- Level of importance
- Responsibility

Using this matrix of work processes and roles, a checklist was developed to determine the opportunities for electrical contractors. This checklist of opportunities was verified and finalized with the ELECTRI-NECA taskforce.

## 6.3. CONCLUSIONS

This section focuses on conclusions reached, based on this research. It is the belief of the author that the evolution of the existing grid into a smart grid provides numerous opportunities for electrical contractors. The smart grid can be seen as the merging of the power system with information technology, to allow an interactive system; that is, at its completion, it will enable easy participation and feedback by all participants in the grid system, from the generation plant to the consumer.

The merging of information technology and electrical engineering is bringing companies who have traditionally been thought of as computer software or hardware companies into the power sector. Companies like Google's and Cisco's emergence into the power sector bring both threats and opportunities for electrical contractors in all sectors of the grid. The companies who avail themselves to this paradigm shift will be well placed to take advantage of the electric construction industry's future. The future power systems will involve partnerships and mergers between several grid participants.

### 6.4. AREAS OF FUTURE RESEARCH

This section deals with ideas for future research related to this arena. In the author's opinion, the following are promising paths for potential research in the coming years:

1. **Interdisciplinary Approach to Construction Management:** Smart grid installation has introduced several companies with little experience in the installation of electrical components. There is the need to develop a comprehensive decision-making framework to assist would-be owners and utility companies in making better-informed decisions in choosing delivery systems, vendors and construction management processes for smart grids.
2. **Retrospective Study:** The CM and installation aspects of smart grids developed for this research were verified by the industry task force. Future research should study the specific magnitude of the effects of the proposed aspects.
3. **Business Plan:** Based on the opportunities identified for electrical contractors, research need to be undertaken to explore the development of a capability

statement for electrical contractors to be able to present themselves to potential owners.

4. **Interdisciplinary Research:** Smart grid activities are being undertaken in isolated terms, limited to the academic discipline—e.g. electrical and electronic engineering research on grid technologies. More interdisciplinary research should be done to understand smart grids on a broader scale.
5. **Consumer Habits:** Further research should be undertaken to assess how the consumption habits of consumers are affected by the introduction of smart components in the home.
6. **Integrating Software and Construction Management:** Further research should be done on integrating global mapping software, like GIS and GPS technologies, with existing construction management software, like Primavera Project Management.
7. **Renewable Energy and Smart Grid:** Further research need to be undertaken to explore the opportunities for energy for integrating renewable energy sources into smart grids systems.

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