

# Key Smart Grid Applications

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## 1. Abstract

The culmination of attention by utilities, regulators, and society for smart grid systems to address operational and electrical efficiencies, improving system reliability, and reducing ecological impacts, has resulted in a significant number of discussions around the requirements and capabilities of a Smart Grid. This session will explore three key Smart Grid functions with the strongest business case justification.

- Delivery Optimization
- Demand Optimization
- Asset Optimization

In addition to technical functionality, the incremental costs and benefits for each example will be presented. This session will include a review of example system architectures and specific functionality to provide improvements to performance metrics, capital and O&M costs and reduction to environmental concerns.

## 2. Introduction

Times are changing. More information about the many forces behind these changes is being published every day.

- It is expected that the demand for electric energy will triple by 2050<sup>1</sup>.
- Digital-quality power which represents about 10% of the total US electrical load will reach 30% by 2020.
- Rolling power outages in developing countries, previously just an unwelcome fact of life, have escalated to the level of “national emergency”.
- Distributed generation including renewable and sustainable power has grown and is expected to double every three years<sup>2</sup>.
- The average age of Power Transformer in the US is estimated to be 40 years old.
- Generation of electricity accounts for 40% of the US’s CO2 emissions<sup>3</sup>.

<sup>1</sup> Source: U.S. Army Corps of Engineers ERDC/CERL TR-05-21

<sup>2</sup> REN21 2007 update + EER

<sup>3</sup> EPRI, “Electric Sector CO2 Impacts, February 2007”, Carbon Dioxide Emissions from the Generation of Electric Power in the United States, July 2000, DOE



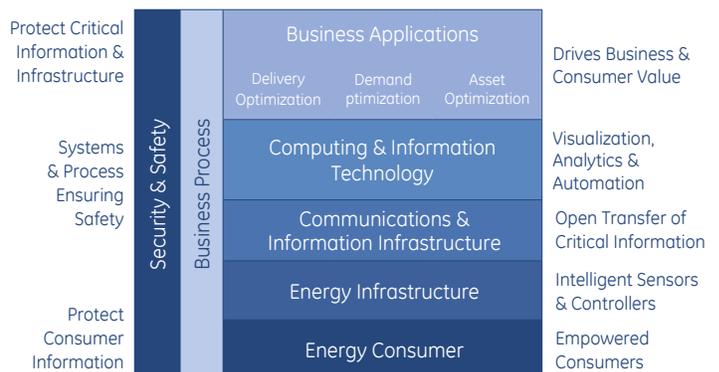
For several years, electric utilities have been turning to Smart Grid technologies to help deal with these pressures. Currently utilities are focusing their efforts on three major areas.

**Delivery Optimization** consists of the efforts by the electric utility to improve the efficiency and reliability of the delivery systems.

**Demand Optimization** focuses on solutions to empower the end consumer and to better manage the evolving demand and supply equation along the distribution feeder

**Asset Optimization** is the application of monitoring and diagnostic technologies to help manage the health, extend the useful life and to reduce the risk of catastrophic failure of electrical infrastructure.

### A Smart Grid drives value with integration of open technologies.



**Figure 1.**  
Smart Grid Technologies

Figure 1 highlights the relationship of the various major functions involved with most Smart Grid solutions. The business applications of Delivery, Demand and Asset Optimization are part of the highest value smart grid business applications. They work on a structure that includes computing and information technology designed to support the applications and help manage the significant amount of data required for each of the applications to function appropriately.

Since the source for much of the data lies outside the utilities data center, an open, secure and powerful communications and information infrastructure is required to access the data. The communications infrastructure touches portions of the entire energy infrastructure from generations to the meter and in many cases into the energy consumer's premise. This system is designed in a way that maintains a high level of safety and security.

### 3. Smart Grid Solutions

Architectures for solutions that focus on each of the three areas will be presented including a summary of functionality and value.

#### 3.1 Delivery Optimization

Delivery Optimization includes two major areas which will be reviewed separately, Efficiency and Reliability.

Utilities have deployed methods to improve the efficiency of their electrical systems. This discussion will focus on recent efforts to change the methods of controlling voltage and VARs on their distribution systems.

##### Efficiency

There are two types of losses in electrical systems, resistive and reactive. Typically, capacitors are deployed in the station and along the backbone of the feeder to help manage the reactive losses and support the voltage. Distribution capacitors are usually operated by local controllers based on Powerfactor, load current, voltage, VAR flow, temperature, or the time (hour and day of week). Through the use of communications to modern controllers, coordinated VAR Optimization is available. This type of system usually controls the line capacitors based on the Powerfactor measured at the substation. Depending on the feeder's load, quantity of capacitors and existing type of control, the system can reduce the electrical losses.

There are two example architectures for these functions as shown in the following diagrams.

With the addition of communication and smart controllers to various voltage regulators and transformer load tap changers, utilities are taking finer control of their feeder's voltage with a technique called Conservation Voltage Reduction (CVR).

Controlling the regulator and LTC, the utility can reduce feeder voltage levels and depending on the amount of resistive and linear loads along the feeder, will reduce the load at the substation. Utilities have seen a 1% reduction for a 4% reduction in voltage.

The architecture shown above illustrates a system where the communications from the distribution devices communicate with the substation. This system utilizes a station based system which operates the line devices for VAR or voltage control based on the measurements at the station and along the feeder.

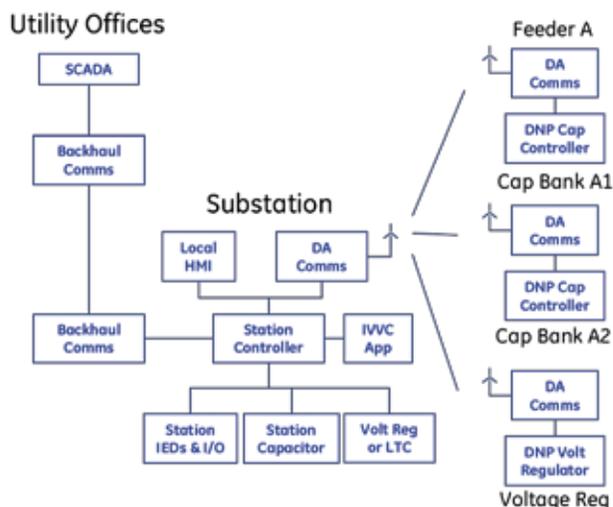


Figure 2. Station Based IVVC System

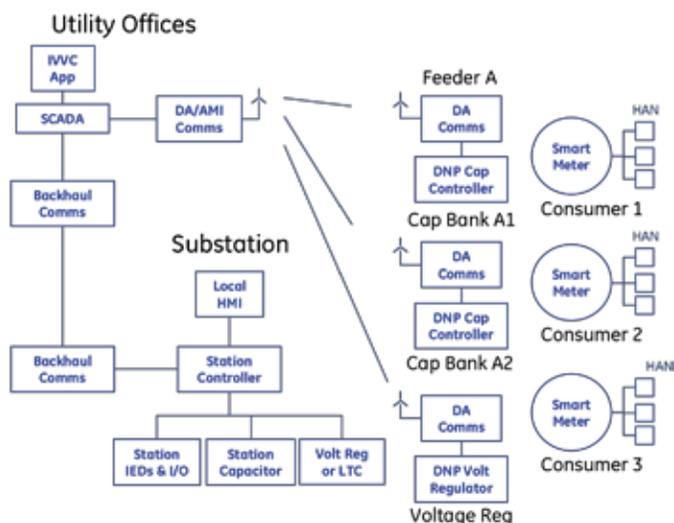


Figure 3. Centrally Based IVVC System

The next system illustrates a centrally based communications system and a centrally located algorithm. This system adds the ability to monitor the voltage from selected customers' meters. The customers selected for voltage monitoring are those at the end or at low voltage points of various line segments. Depending on the AMI system's latency and bandwidth, selected meter voltage reads are incorporated into the IVVC application to allow for a wider operating range of the CVR application.

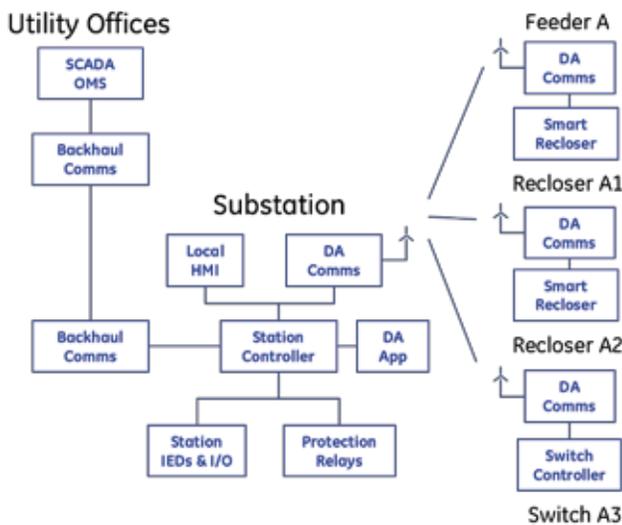
The capacitor communications can utilize a separate DA system communications or can share the AMI communications network and backhaul. Both systems require communications with the substation for control and monitoring of station transformers and feeders. Some utilities have estimated the aggregate payback for an integrated volt/VAR control system to be less than two years. These benefits can be significant and are typically shared between the utility and the end consumer depending on the rate structure. Regulating Commissions are becoming more and more receptive to granting a portion of these benefits to the utility to help compensate for the expenses of the systems. The balance

of the benefits often flow through to the end consumer in the rate making process. The benefits typically include:

- Improved distribution system efficiency
- Reduced distribution line losses
- Improved voltage profile along feeder
- Improved system stability and capacity
- Deferred capital upgrades
- Reduced energy demand
- Reduction of environmentally harmful emissions

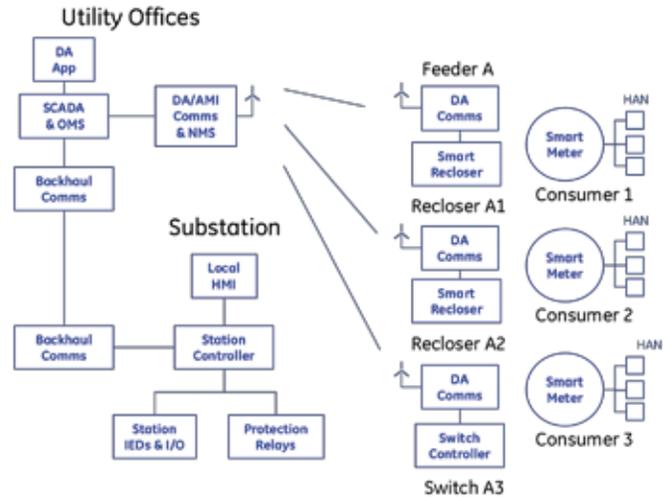
### Reliability

Many utilities are turning to Smart Grid applications to provide improvements to reliability metrics. Two typical architectures are shown below. The first shows a station based automation system with smart devices installed in the substation and in distribution circuit reclosers, or switches for underground systems. Faults are detected between switches and are isolated under control of the automation system. Unfaulted sections of the feeder are restored from alternate sources depending on available sources and their capacity to carry the additional load.



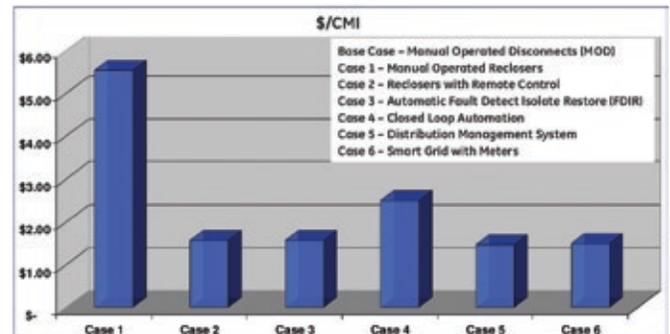
**Figure 4.**  
Station Based Distribution Automation

The architecture shown below uses a centralized distribution automation system with the addition of communication to smart metering. The algorithm can utilize the information from the smart meters to assist in detecting outages outside of the monitored range of the automated devices. This includes fuses or other non-automated fault interrupters. The meters can detect and report an outage and can report successful restoration. Using the restoration detection, the system can determine customers have been properly restored as expected. After restoring customers after a fault, any meters not responding with a restoration can indicate a possible nested outage. This capability can significantly improve the time to respond to these outages.



**Figure 5.**  
Centralized Distribution Automation

Many regulators do not provide the utility with direct incentives for investment designed to reduce outages, however rely on the threat of penalties to encourage investments. This makes it prudent for the utility management to apply automation to the most troublesome circuits first. However, it is also necessary to determine the appropriate level of automation to be applied. The following chart compares the costs per improvement to customer minutes interrupted compared to a typical non-automated base case circuit.



**Chart 1.**  
System Costs by Customer Minutes Interrupted (CMI)<sup>4</sup>

In this study, the Base Case consists of 2 Manual Operated Disconnect Switches (MOD) and a shared tie switch with another feeder. Case 1 changes the MODs to manual operated reclosers on overhead circuits and customers on that circuit experience a corresponding improvement to outage minutes. Case 2 adds communications to the reclosers, allowing the dispatcher remote manual control to of the switches. Cases 2-6 have a significant improvement to reliability metrics from the ability to localize faults and isolate and restore unfaulted segments of the feeder. Case 3 adds the ability for automation software for Fault Detection, Isolation and Restoration (FDIR). Case 4 utilizes an expensive but highly effective automation system where the normally open tie switch is normally closed. This closed loop automation

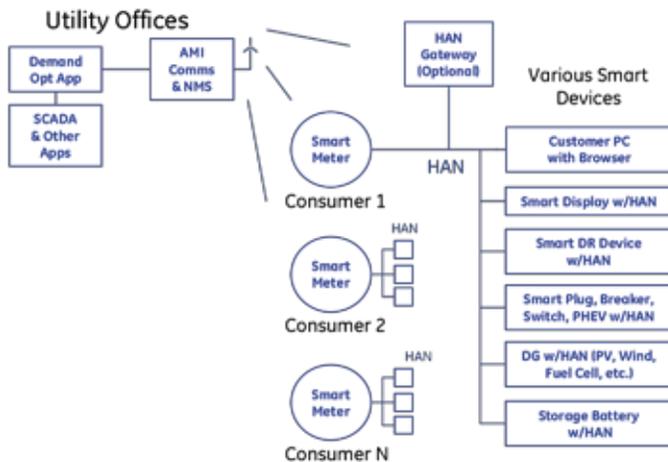
<sup>4</sup> Justifying Distribution Automation at OG&E, by Cristi Killigan and Byron Flynn, prepared for DistribuTECH 2009

circuit requires expensive dedicated high speed communications between the switches to prevent over-tripping. Case 5 adds the ability to utilize a centralized automation system with the addition more sophisticated electrical network model supporting the automation software. Case 6 adds the ability to detect outages/restoration from the meters.

### 3.2 Demand Optimization

In recent years, Demand Optimization has generated a significant amount of interest. This solution has drawn the attention of regulators and the US federal government. Often the benefits from Demand Optimization is what is in mind when regulators installation of smart metering. These are the benefits most directly experienced by the end consumer.

Solutions around Demand Optimization are varied and range from simple advanced metering systems to full home automation. The figure below is designed to highlight the possibilities of a solution.



**Figure 6.**  
*Demand Optimization System Architecture*

This system usually consists of several different devices in the consumer's home, usually at a minimum it includes a smart thermostat connected to a smart meter. Often the consumer connects their PC to a web page containing information about their usage and available programs the consumer can select.

Addition of a Smart Display allows continuous communications between the utility and the end customer. These displays can be simply a light which changes color based on time of use rates or can be a complex full graphic color touch screen connected to a full home automation system. New smart appliances, wall switches and wall sockets are beginning to become available for integration into a Home Automation Network (HAN). Some systems integrate local generation into the home including Photo Voltaic, solar panels, small wind generation, or more exotic systems such as fuel cells.

The architecture above also includes an optional HAN gateway. This gateway is intended to allow secure connection between the utility systems and the consumer's HAN when the communications to the end meter is not robust enough to handle the utility-HAN communications. In this option, the HAN gateway is connected to a customer's broadband Internet connection, providing a higher bandwidth connection than may be possible through some of the legacy slower speed AMI systems.

The following is a partial listing of example choices, programs, and devices which consumers and utilities are electing to deploy around Demand Optimization.

#### Empowering Customer Choice & Control:

- Critical Peak Pricing
- Time of Use Rate
- Green Power Choices
- CO2 Management Choices
- Prepaid Metering
- Voluntary or Automatic Control of Energy Demand
- Usage Management – by Appliance
- Home Energy Management
- Net Metering, collecting KWH, KVARH, Voltage,
- Power Quality

#### Providing Security & Safety Management:

- Energy Theft
- Tamper Detection
- Visual inspection during installation
- Monitoring and baselining usage patterns
- Interruptions and usage pattern changes
- Detect load-side voltage with disconnect

#### Enabling Distributed Generation:

- Photo Voltaic (Solar)
- Wind
- Biomass
- Geothermal

#### Incorporating Distributed Storage:

- Li-Ion Battery
- Fuel Cells
- Plug in Hybrid Electric Vehicle (PHEV as a storage device)

#### Facilitating New Programs and Capabilities:

- Load Management Programs
- Demand Response Program
- Distributed Generation
- Storage Management
- Automatic Meter Reading
- New Communications with Customer

- Power Quality Management
- Remote Service Switch
- Cold Load Pickup
- System Cyber Security
- System Management

The value of a TOU and CPP program has been estimated for a 6% peak load reduction as shown below.<sup>5</sup>

- \$26 MM/yr O&M and capital expenditure reduction
- 126 GWh generation reduction
- Consumer's savings: up to 10%
- 57K tons of CO2 reduction
- Estimated capital cost of \$12MM
- Estimated O&M cost of \$11MM/yr

### 3.3 Asset Optimization

Much of the modern electrical system was installed over 40 years ago. Unfortunately, many devices in the system are frequently being pushed to operate at overload conditions. One of the single most expensive pieces of the distribution system is the station power transformer. Given that the general life expectancy of power transformers is around 40 years; this can result in a risky and expensive challenge.

The architecture shown below illustrates how Asset Optimization solutions can be added to a Smart Grid.

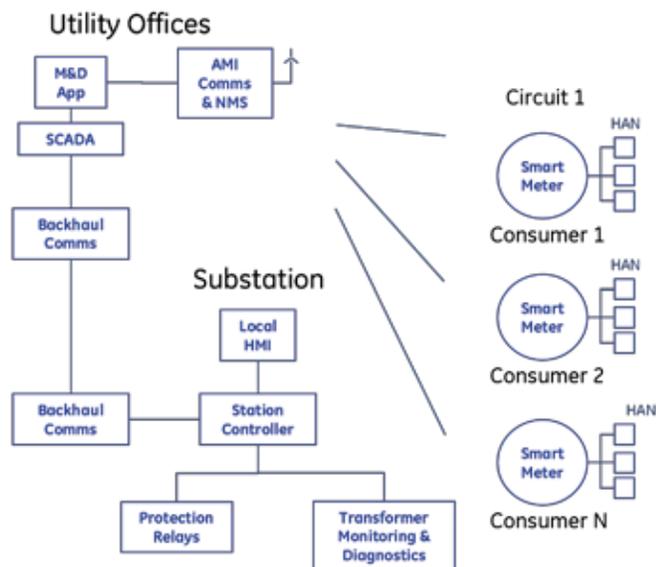


Figure 7. Monitoring and Diagnostics (M&D) System Architecture

The architecture includes monitoring and diagnostics on the primary station transformer, station breaker, and distribution feeder devices.

The monitoring and diagnostics of the station transformer can include simply monitoring temperatures or continuous monitoring of the oil for combustible gasses and moisture. Advanced monitoring today can calculate internal hot spot temperature, the transformer dynamic load ability and future capacity over time, the insulation aging factors and data from many other models.

Monitoring of the station or line protection relays provides valuable information regarding the health of the breaker including operating times, total interrupted fault current, and operation counts.

Data collected from the meters can help determine near realtime loading on the distribution cables, especially the underground cables, and loading on the local distribution transformers.

This can help distribution engineers improve the distribution planning and design and help rebalance the load along the phases.

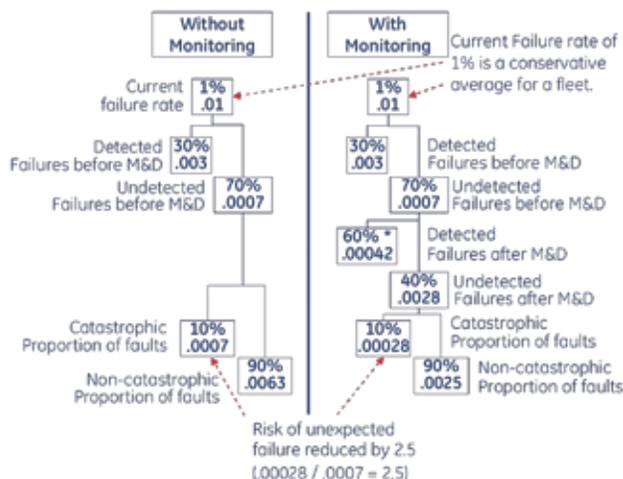


Figure 8. Transformer reliability comparison<sup>6</sup>

The figure above contains the comparison of the power transformer failure rates with and without monitoring. For transformers without monitoring, the risk of catastrophic failure is approximately .07% and for transformers with on-line monitoring and diagnostics it is .028%, resulting in a reduced risk of failure of 2.5 times.

For example, if an average electric utility with 1 million customers, installed an M&D system which monitored the dissolved gas, temperature and load on their the transformer fleet, rated 20MVA and above, the costs and benefits is determined as follows:

An annual capital expenditure savings of \$12MM/yr with an investment of \$42MM in capital and \$1.2MM/yr in additional maintenance. These numbers would result in a net present value, using 8.7% over a 15 year system life, of over \$54MM.

<sup>5</sup> Based on avg. 1 MM customer utility, California Statewide Pricing Pilot, June 2006

<sup>6</sup> 60% is an industry accepted effectiveness number for a quality monitoring system. The failure reduction figure is based partly on a CIGRE study. As an additional reference, a study conducted by one of KEMA's utility client shows that Distribution Automation projects can reduce the costs of repairing substation transformers by 67%.

## 4. Summary

While each of these solutions can have significant benefits to an electric utility and their consumers, elements of each can be leveraged for uses outside those stated in the previous discussions.

For instance, an IVVC system installed to control the VARs and volts can coordinate with a DA system installed to improve reliability. The rerouting of the distribution system to restore unfaulted sections of a feeder can significantly change the voltage and VAR profile of that feeder. If the IVVC system is operating on the same system network model as the DA system, it can continue to control the VARs and volts in the temporarily reconfigured distribution system.

Coordinating the asset management system to work with the DA system can result in new options to dynamically move load off of overloaded equipment by moving the normally open tie between different feeders to different locations. If the systems are working on the same network model, the DA system can continue to operate to improve reliability on the newly reconfigured network.

Furthermore, the CVR functions in the IVVC system should be coordinated with the Demand Optimization systems to maximize the benefits of improved load management. Depending on the a number of factors such as rates, prices, and system loading, the utilities' operations staff can pick the most cost effective method of reducing load by lowering voltage, issuing an automatic demand response signal and/or changing the consumer's time of use rate.

leverage elements of the network model in the office and can share data with other utility systems utilizing standards based methods.

## 5. References

Papers from Conference Proceedings (Published, or pending publication):

- [1] Dalton, Howard, and Flynn, Byron, "SCADA Integrated with Transformer Monitoring Systems over a Secure Wireless Ethernet", 2005 DistribuTECH Conference and Exhibition, San Diego, California January 25-27, 2005.
- [2] Flynn, Byron, "Case studies regarding the integration of monitoring & diagnostic equipment on aging transformers with communications for SCADA and maintenance", DistribuTECH 2008, Conference and Exhibition, Tampa Convention Center, Tampa, FL, January 22-24, 2008.
- [3] Flynn, Byron, "Secure Substation Automation Architectures for Operations & Maintenance", 2006 DistribuTECH Conference and Exhibition, Tampa, Florida, February 7-9, 2006.
- [4] Flynn, Byron, "What is the real potential of the Smart Grid?" Autovation 2007, The AMRA International Symposium, Reno, Nevada, September 30 - October 3, 2007.
- [5] Lathrup, Steve, and Flynn, Byron, "Distribution Automation Pilot at PacifiCorp", Western Energy Institute, 2006 Operations Conference, Costa Mesa, CA, April 5-7, 2006.
- [6] Stewart, Robert, and Flynn, Byron, "Modeling DA Improvements to Reliability Performance Metrics", 2007 WPDAC, Spokane, Washington, April 3 - 5, 2007.

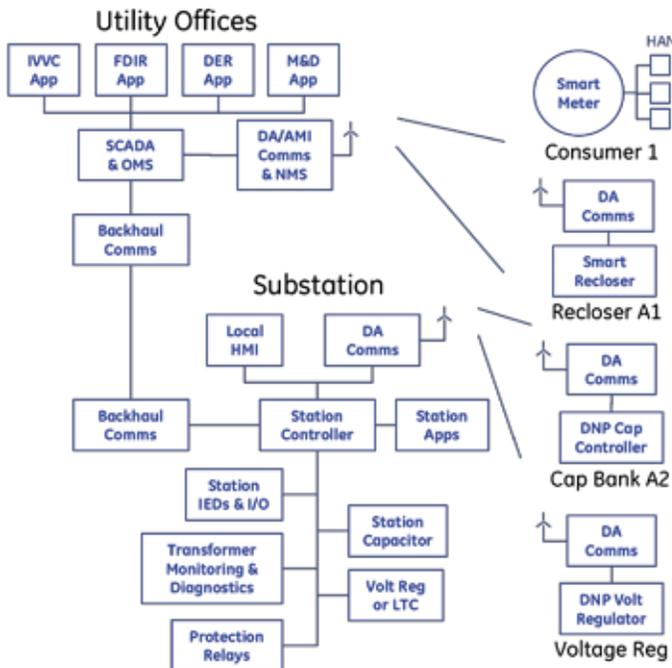


Figure 9. Smart Grid System Architecture

The architecture of a fully integrated system as shown above is represented in the above figure. Properly designed using open interoperable products and techniques, the various systems can minimize the amount of duplication, can more easily integrate with existing utility infrastructures, can more effectively share communication infrastructure across the system, can share