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AMI and DA Convergence: *Enabling Energy Savings through Voltage Conservation*

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Table of Contents

Executive summary	Page 3
Convergence of distribution automation and advanced metering infrastructure	Page 4
Overview of voltage conservation	Page 4
The role of AMI in voltage conservation	Page 6
How voltage conservation works	Page 7
Benefits of voltage conservation	Page 9
Conclusion	Page 10
Glossary	Page 11

Executive Summary

The convergence of advanced metering infrastructure (AMI) and distribution automation (DA) is providing opportunities for beneficial power grid modernization. In no application is the potential for both utility and customer benefit greater than voltage conservation to reduce energy use on power distribution systems. As a benefit to the utility, voltage conservation reduces distribution system losses while maintaining power quality throughout the distribution system. The reduction in voltage is transparent to the consumer; power quality is maintained, voltage stays in the recommended range, and household appliances operate as designed. The important benefit to consumers is that – without the need for any change of behavior – they will actually consume less energy resulting in lower household electricity bills. The energy reduction translates into less power generation, and hence fewer greenhouse gas emissions.

Historically difficult and impractical due to the utility's inability to cost effectively monitor voltage levels continuously at the residential meter, voltage conservation is now possible – using smart grid technology that bridges AMI and DA. This paper describes voltage conservation, the role of AMI in voltage conservation, how voltage conservation works, and its benefits. The paper provides an overview of how Elster's EnergyAxis® Smart Grid solutions facilitate voltage conservation – a capability not available from many competing systems.

Convergence of distribution automation and advanced metering infrastructure

The convergence of distribution automation (DA) and advanced metering infrastructure (AMI) promises a range of benefits to electric utilities and their customers. DA is widely defined as a set of technologies that enable an electric utility to remotely monitor, coordinate, and operate distribution components in a real-time mode from remote locations. Today, the missing link in DA at many electric utilities is effective and pervasive communications systems. Without such systems, “remote” capabilities are nonexistent. Because of this lack of installed communication infrastructure, many utilities today have little or poor visibility outside of the distribution substation down to the customer. From these substations, utilities are currently able to monitor and control a small number of locations on feeders, and perhaps some large commercial/industrial customers, but their reach ends there.

Ultimately, no single technology or system meets the combined demands of DA and AMI; technologies and systems must be interoperable and complementary. Smart grid/AMI systems, such as Elster’s EnergyAxis® System, provide the necessary multi-technology communications infrastructure. Hence, the convergence of AMI and DA is the key to realizing the many benefits of grid modernization and the smart grid. AMI and DA can and must work together as a unified system. The convergence of DA and AMI requires distributed intelligence, integrated communications, and sensing and measurement, while delivering vastly improved distribution system visibility between the substation and the customer premises. Leveraging this convergence enables various potential applications and benefits such as outage detection and fault location; loss detection; actual load flow and feeder state estimation; power quality monitoring; cost-effective fault isolation, reconfiguration and restoration; and volt/VAR monitoring and control.

Overview of voltage conservation

Of the many potential applications for the convergence of AMI and DA, the low hanging fruit is voltage conservation. All electric utilities stand to benefit significantly from its implementation. Voltage conservation is a method by which utilities strive to lower the voltage on feeders while delivering energy within standards-based voltage limits to all service points. This reduces both transformer and line side losses, as well as losses in customer equipment. Overall, voltage conservation reduces the amount of power needed to service a given customer base. Historically used to reduce loading during peak demand periods, voltage conservation efforts are now gaining acceptance as an energy cost reduction method.

This reduction in voltage has no power quality or service impact on end customers; that is, consumers do not perceive that a voltage reduction has occurred because the voltage at the meter remains within acceptable ranges. Consumers will actually use less energy with no additional effort or understanding on their part – reducing household costs and improving customer satisfaction.

ANSI C84.1 of the American National Standard for Electric Power Systems and Equipment for Voltage Ratings establishes nominal voltage ratings and operating tolerances for 60-Hertz electric power systems above 100 V through 230 kV. Table 1 shows the preferred range and infrequent range for both service voltage and utilization voltage. This shows that the preferred service voltage extends as much as 5 percent lower than the nominal 120 volts.

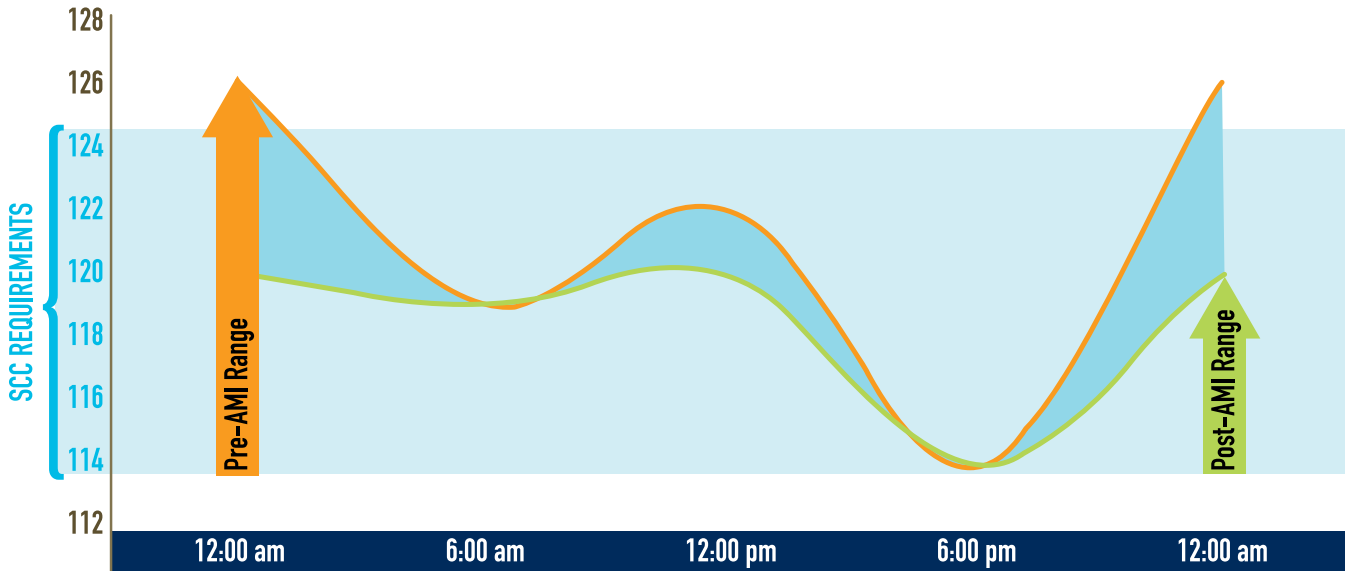
	Range A (Preferred)	Range B (Infrequent)
Service Voltage	114 – 126	110 – 127
Utilization Voltage	110 – 125	106 – 127

Table 1. ANSI C84.1 voltage tolerances.

The goal of voltage conservation is to reduce energy losses and consumption by operating at the lower end of these voltage ranges. Figure 1 shows a typical daily

voltage curve for a residential customer. The top line (orange) shows the voltage level over the typical day prior to voltage control. The bottom line (green) shows the voltage level after voltage conservation is implemented (leveraging an appropriate AMI system). Note that voltage conservation does not lower the voltage level during periods when voltage is already low (e.g., 6:00 am and 6:00 pm). However, it does lower voltage when the level is unnecessarily high. The shaded area between the two lines represents the amount of voltage reduction, and the proportionate reduction in energy use.

Figure 1. Impact of voltage conservation on a voltage profile for a typical day at a typical residential customer



The amount of reduction in energy use for a given reduction in voltage varies by the type of loads involved. For example, power use in a resistive load (i.e., a load with heating elements such as electric resistance heating, hot water heaters, stoves and cooktops, ovens, laundry dryers, room heaters, and auxiliary heat strips in heat pumps, etc.), has been shown to vary linearly (or nearly so on average) with the voltage of the load. Although some resistive loads self adjust as voltage across the load is decreased (for example heat strips may be used just a bit longer to deliver the required heat), studies indicate reduction in voltage still results in appreciable savings. Power use in reactive (inductive) loads such as motors, pumps, and compressors may not vary linearly with the voltages supplied to the load. However, reducing voltage on reactive loads and the beneficial impact of reducing reactive power (and hence increase the feeder’s capacity to deliver real power) may be even more significant.

Across a feeder or neighborhood, utilities have found that reducing the voltage does reduce energy use. Table 2 shows how the amount of energy use decreased for each 1 percent in voltage reduction at various utilities. For example, Consumers Power Company found that energy use decreased by 0.83 percent for each 1.0 percent reduction in voltage for residential customers. Table 2 also shows that voltage reduction can be beneficial for commercial loads.

Utility	Percent Demand Reduction for 1% Voltage Reduction	
	Residential	Commercial
American Electric Power 1	0.80	0.78
American Electric Power 2	0.90	0.86
Consumers Power Company	0.83	1.38
San Diego Gas & Electric Co.	1.14	0.08

Table 2. Voltage reduction test results at four utilities show the decrease in energy use for a 1 percent voltage reduction. Source: Power System Voltage Stability by C.S. Taylor, McGraw-Hill, Inc.

The role of AMI in voltage conservation

In view of these results, why haven't more utilities implemented voltage conservation?

Voltage conservation is not a new concept. Many utilities have been monitoring and controlling voltage in substations, on select feeder locations, and at large commercial/industrial customers for a long time. But extending this capability through the power distribution networks down to the individual residential and small commercial customer level has been problematic.

Customer-level voltage conservation requires an AMI system that can gather the voltage data and provide various alarm and feedback mechanisms to monitor the voltage in real-time at customer end points. Without advanced metering and pervasive communications systems, utilities cannot monitor voltage at the customer level. They are limited to voltage monitoring and control at distribution substations and a small number of other locations.

Utilities must ensure that all customers receive power at an acceptable voltage. The customer at the very end of the circuit or other discrete points on the system may drop out of voltage tolerance due to variations in distribution circuit equipment, wiring, and other causes. Lacking visibility into the voltage levels of all customers, the utility must operate the system conservatively, which usually results in unnecessarily high voltage levels for some or even most customers during some periods of time during the day.

Even if a utility has installed an AMI system, they may not be able to effectively implement voltage conservation. Not all AMI systems and their building blocks — the advanced meters themselves, for example — provide the capabilities needed to support voltage conservation.

The crucial enabling technology for adaptive voltage conservation is the ability to monitor individual customer voltage levels and energy use data to operate the power distribution system within a tighter tolerance. To do this, the AMI system must continuously monitor the lowest voltage customer, and provide this data with the cycle time necessary to adjust voltage. The system must do this without adding limitations or constraints to other core AMI applications such as meter data collection, turn-ons/turn-offs, on-request reads, alarms, or other real-time system requirements. This requires that the AMI system and its advanced meters be specifically designed for voltage conservation.

Transmission and distribution energy losses of up to 7 percent are common on electric utility systems. Figure 2 shows the locations of these losses. Voltage conservation focuses on the portion of the system where the

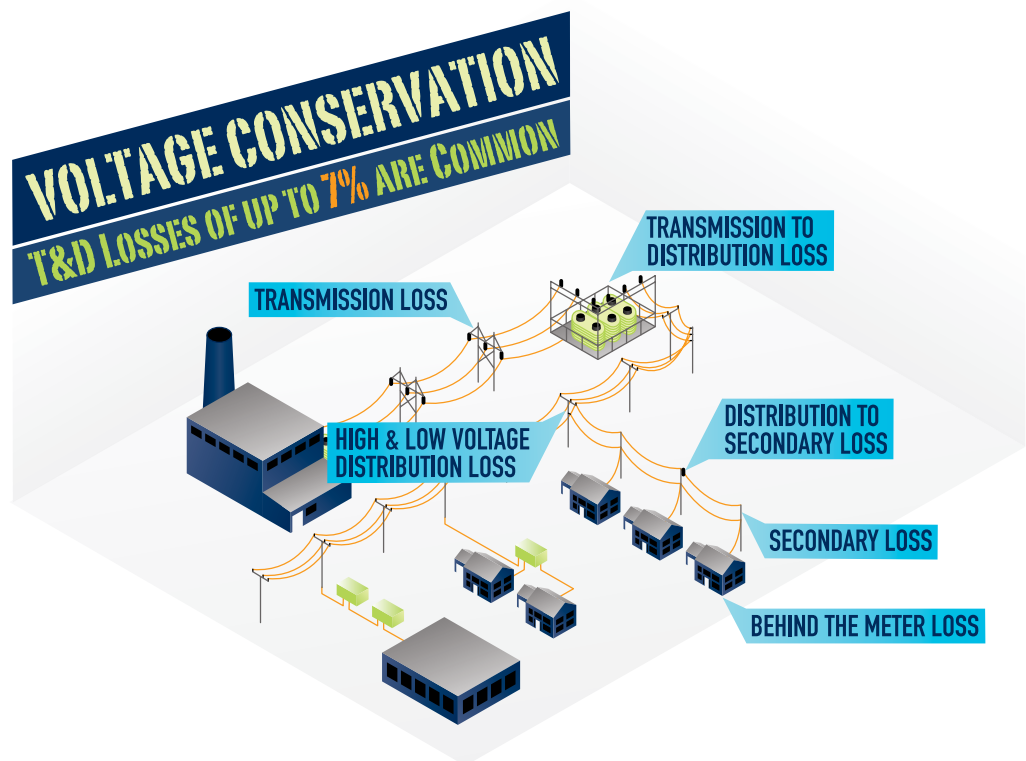


Figure 2. Types of energy losses on transmission and distribution systems

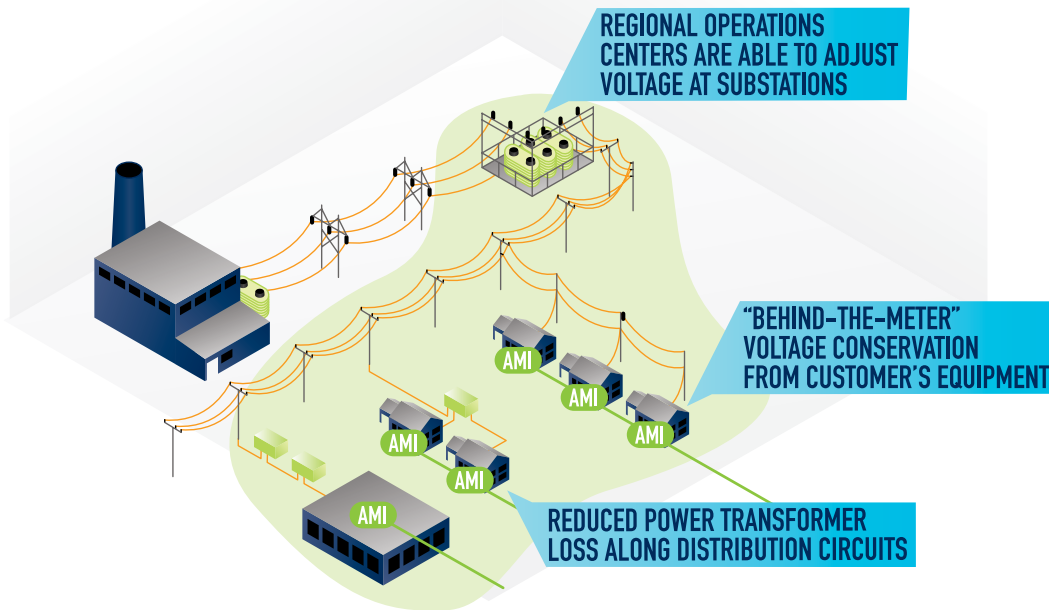


Figure 3. The role of AMI in enabling voltage conservation

losses are the greatest and where voltage has not traditionally been monitored and controlled: through the power distribution network to the customer.

Figure 3 shows the role of AMI in facilitating adaptive voltage conservation at the customer level. Reducing the voltage on distribution systems reduces distribution transformer losses and decreases customer energy use. While all generations of distribution systems benefit from voltage conservation, older distribution systems benefit even more than relatively new ones.

How voltage conservation works

In the electric power industry, Elster's EnergyAxis System incorporates customer meters that monitor voltage on a regular basis. Installation of these meters ensures adequate visibility into the range of customer voltages that occur at various locations on feeders. The Elster EnergyAxis System monitors selected key points frequently and harvests that data in near real time.

In addition, the meter provides a safety net. It has the capability to send an alarm message whenever line voltage at any customer site drops below a pre-defined limit for a configurable qualification time. This ability to detect voltage fluctuations in real time at all endpoints allows the system to identify and adjust the monitoring algorithms. This provides assurance that the voltage data is being collected from the points necessary to

ensure proper voltage service levels across the entire distribution system.

When an alarm message is generated, the EnergyAxis head-end system forwards the alarm information to the utility's Distribution Management System (DMS)/Supervisory Control and Data Acquisition (SCADA) system. This system processes the incoming voltage data, giving system operators the information they need to initiate strategic mitigating actions. These actions may include switching in or out a capacitor bank, or tapping a load tap changer (LTC) up or down to maintain the voltage profile at a proper level. This response can be manual or automatic, using systems such as the Yukon[®] Advanced Energy Services Platform (from Cooper Power Systems) for automated capacitor bank control (see Figure 4). Additionally, this may trigger circuit analysis to determine if adjustments, such as wiring, or distribution transformer updating, are needed on the distribution circuit.

Frequent voltage reads also provide immediate feedback to system operators to ensure that the voltage adjust-

ments had the desired effect. Because both voltage and energy are recorded for the same time intervals, the system can document energy reduction for each customer and roll up these data on a monthly and feeder basis. This data can be used to evaluate the voltage conservation program and demonstrate conservation levels to regulators.

The system is transparent to customers; they experience the same operating levels as before the implementation. Key customers with critical needs, such as hospitals, can be monitored specifically to ensure no change in power quality.

Elster is one of the first AMI/Smart Grid vendors to offer a system specifically designed for continuous voltage

monitoring at both residential and commercial/industrial customer locations, enabling utilities to implement adaptive voltage control by providing real-time voltage visibility across distribution feeders. In addition to allowing proactive voltage monitoring at various points along the feeder, Elster's system provides 100 percent coverage of the residential base. Through the use of state-of-the-art voltage threshold monitoring, the system provides notification to the utility if any location drops out of prescribed voltage limits. This capability allows utilities to reduce voltages aggressively, with confidence. The Elster AMI system acts as the "eyes" throughout the distribution system, the DMS/SCADA is the "brain" that makes decisions as to mitigating actions, and the capacitor banks and LTC voltage regulators are the "brawn" to implement these actions.

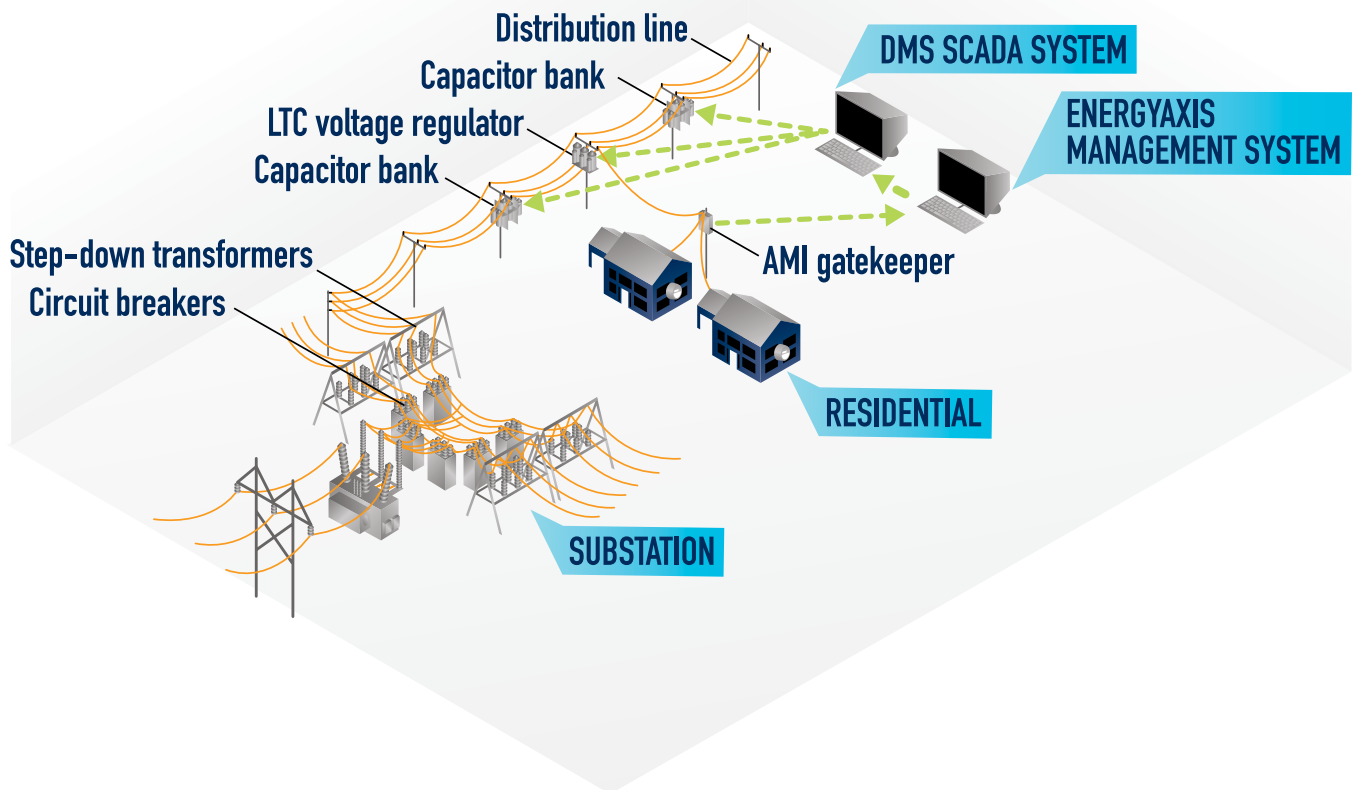


Figure 4. Elster's AMI System Facilitates Voltage Conservation

Benefits of voltage conservation

Potential benefits of effective voltage conservation include customer energy savings, deferred utility capital investment in unnecessary power generation, and savings resulting in longer equipment life for utilities and customers.

A large eastern U.S. utility is currently demonstrating the potential energy savings of an installed Elster EnergyAxis System as a key component of its voltage conservation program. This utility projects a 0.8 percent reduction in energy use for each volt reduction at its substations on average. One substation sees a 1.0 percent reduction for each volt conserved, thus validating the experiences of other utilities. The utility estimates that the voltage conservation project will reduce their overall losses by 20 percent (from approximately 7 percent to about 5.6

percent). For a utility of this size, this will result in more than 1 million MWh/year of reduced energy losses.

This is equivalent to a 460 MW renewable energy resource operating at a 25 percent capacity factor. The comparison to a renewable resource is appropriate because the reduced losses, like renewable energy sources, displace fossil-fuel-fired generation in many cases. Because the reduced losses translate into less power generation, this also results in annual reductions of 686 metric tons of carbon, 4 metric tons of methane, and 7 metric tons of NO_x emissions. (The greenhouse gas emission calculations are based on the U.S. median for energy sources.) After installing thousands of meters that can monitor voltage and initiate alarm messages, the utility concluded that voltage conservation delivered by EnergyAxis is overwhelmingly beneficial for both the utility and their customers.

End consumer benefits are derived in the form of reduced energy consumption and decreased cost. The

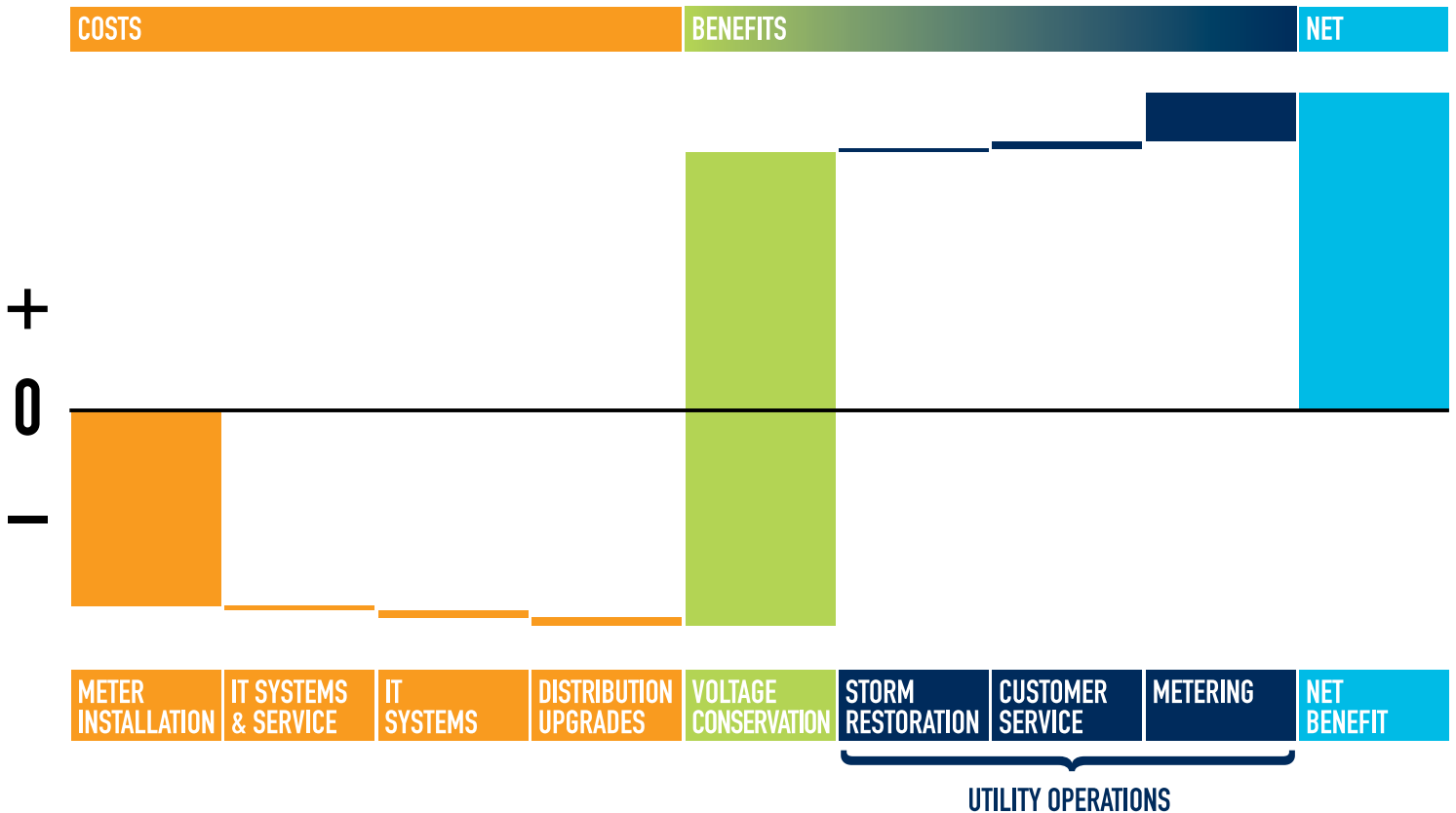


Figure 5. Benefits of Voltage Conservation

consumer will not notice any changes in appliance performance because voltages remain consistently within the preferred range. However, the appliances will consume less energy – reducing energy consumption with no effort by the consumer. Obviously, the extent of the consumer’s actual cost savings will depend on existing household usage patterns, the utility’s use of time-based rates, and the number, age, and efficiency of household appliances and devices.

Figure 5 compares and contrasts the types of business case benefits that are possible when AMI and DA converge. While installation of meters and ancillary equipment constitutes the primary investment, additional small costs include IT systems and service, IT systems, and required distribution system upgrades. The payback from voltage conservation and reduced energy consumption more than compensates for these costs. Additional business case benefits of AMI shown in the figure include improved storm restoration through more rapid response, improved customer service, and more accurate and cost-effective metering.

Benefits not shown in Figure 5 include minimizing damage to distribution equipment caused by overloads, avoiding rate penalties associated with failing to adequately encourage conservation, and adapting to load growth as more customers are added to the power system. Various qualitative and societal benefits include deferred construction of new generation, reduced CO₂ and other greenhouse gas emissions, and reduced reliance on fossil fuels.

Conclusion

Voltage conservation is a proven means of reducing energy consumption on the distribution system; utilities have repeatedly demonstrated its technical and economic viability. Voltage conservation is an ideal smart grid application to leverage the investment in both a utility’s AMI and DA systems by effective convergence of these systems. In fact, voltage conservation is one of the more important applications that utilities should consider as part of their grid modernization efforts. Elster’s EnergyAxis solutions provide the ability—not possible with many other systems—to facilitate voltage conservation.

Glossary

AMI — Advanced Metering Infrastructure — is a network of metering equipment that is typically two-way from a head-end software system to various metering endpoints consisting of electric, water, and/or gas meters or modules. A key differentiator from traditional automated meter reading (AMR) is the focus on two way operation of the network with endpoint configurability. AMI systems are typically fixed network with radio frequency (RF) mesh and tower-based solutions being most prevalent in North America.

DA — Distribution Automation — is a set of technologies that enable an electric utility to remotely monitor, coordinate, and operate distribution components in a real-time mode from remote locations.

Head-end system or System head-end — in the context of this paper refers to the software and servers which manage the AMI network and which typically integrate with various utility enterprise level systems.

SCADA — Supervisory Control and Data Acquisition — refers to a system that collects data from various sensors, such as along the distribution network, and then sends this data to a central computer which then manages and controls the data.

Voltage conservation — is a method by which utilities strive to lower the voltage on feeders to the extent possible while still delivering energy at voltages within standards based limits to all service points. This reduces both transformer and line side losses, as well as losses in customer equipment, thus reducing the amount of power needed to service a given customer base.