Appendix B3:
A Systems View of the Modern Grid

ADVANCED COMPONENTS

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EXECUTIVE SUMMARY

The United States urgently needs a fully modern power grid if we are to meet our country's growing requirements for reliability, security, efficiency, cost of service, and environmental responsibility.

To achieve a modern grid, a wide range of technologies must be developed and implemented. These technologies can generally be grouped into five key technology areas as shown in Figure 1 below.

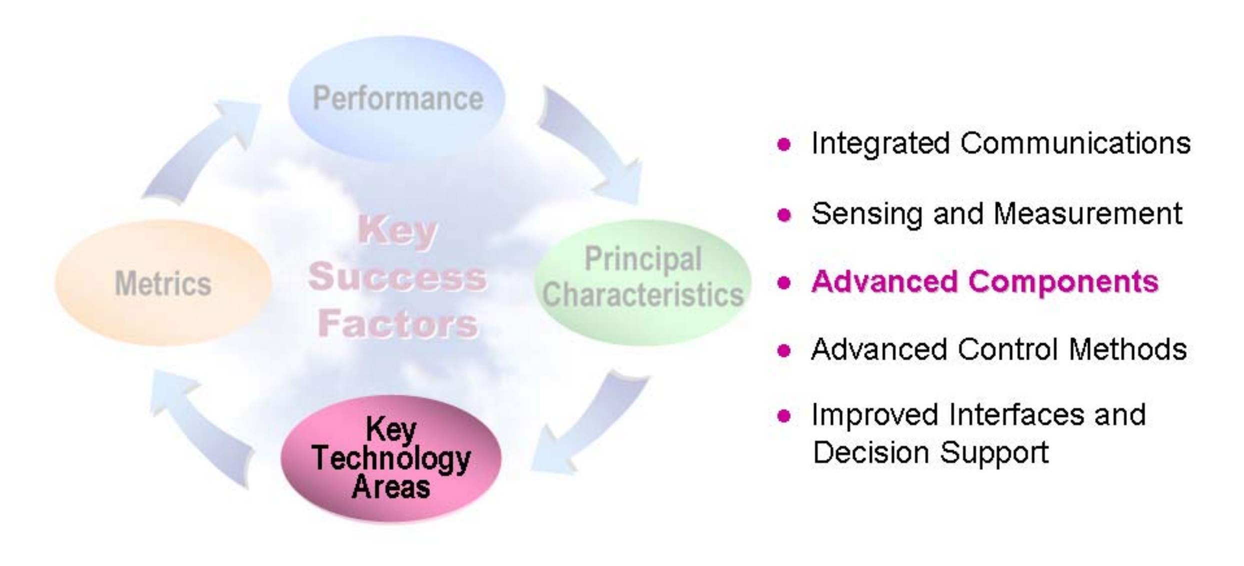


Figure 1: A Systems View of the Modern Grid provides an "ecosystem" perspective that considers all aspects and all stakeholders.

Advanced components play an active role in determining the electrical behavior of the grid. They can be applied in either stand-alone applications or connected together to create complex systems such as microgrids. These components are based on fundamental research and development (R&D) gains in power electronics, superconductivity, materials, chemistry, and microelectronics.

Unfortunately, the needed grid-related R&D in the United States has dropped to unacceptably low levels, particularly since the drive began to restructure the industry. Should this trend continue, the U.S. economy will suffer severely from the absence of a suite of advanced components that would elevate the existing North American grid to world-class status.

Another barrier to the development and implementation of advanced components is the high cost involved in developing them. This, combined with the lack of clearly articulated argument for them, has had a chilling effect on the investment community.

Stakeholders must come to understand the worth of implementing key technologies such as advanced components. These technologies are critically important to the supply of electric power, allowing greater economy, safety, cleanliness, and reliability than is currently possible. To achieve a truly modern grid, we must have buy-in from all stakeholders.

This paper will cover the following important topics:

- Current state of advanced components
- Future state of advanced components
- Benefits of implementation
- Barriers to deployment

Although it can be read on its own, this paper supports and supplements "A Systems View of the Modern Grid," an overview prepared by the Modern Grid Initiative team.

CURRENT STATE

We will now discuss the current state of various advanced components, as well as the core technologies upon which they depend.

We must keep in mind, however, that while all of these technologies and components are needed for a modern grid, the timetable of expected availability varies.

Power Electronics in Transmission and Distribution Systems

Flexible alternating current transmission system devices (FACTS devices include UPFC, DVAR, SVC, etc. See Table 1) are good examples of advanced components that are based on power electronic technologies. FACTS have already demonstrated their worth in a number of transmission and distribution (T&D) applications, including the following (*1*).

- Voltage control at various load conditions
- Power quality enhancement
- Reactive power balance
- Stability problems with energy transfer over long distances

High voltage direct current (HVDC), a mature technology, also relies on power electronics to resolve many issues involving the power grid, such as these:

- Coupling of asynchronous systems
- Stability problems with energy transfer over long distances
- Increase of short-circuit currents in meshed systems

All of the advanced components in the following tables are either available today or are under development.

Table 1 shows some of the power electronic devices that are vital to the modern grid vision:

Table 1: Examples of power electronic devices

Power Electronic Devices	
Advanced component	**Description**
Unified power flow controller (UPFC)	• Can fully manage most requirements of reactive power compensation and flow control. • A 345 kV UPFC that incorporates an interline power flow controller addressing congestion issues has been commissioned at NYPA's Marcy substation. • Are available today but, because of their high cost and limited experience base, they have been deployed only sparingly. Broader deployment will take place as technical performance is proven, as costs drop, and as their societal value is recognized.
DVAR or DSTATCOM	• Mobile, relocatable, insulated gate bipolar transistor (IGBT) device that can be sited at system or industrial interfaces. • Provides voltage support, reduces industrial flicker, provides improved power quality, mitigates wind generator impact on transmission lines, and a variety of other applications. • Has had fairly wide acceptance and deployment.
Medium voltage static voltage regulator (MV SVR)	• Boosts whole-facility load voltage during source voltage sags caused by faults in the utility distribution grid or in the transmission system. • Load voltage boost performed within a quarter to half cycle, enabling even the most sensitive facility equipment to ride through sag events without operational disruptions.
Static VAr compensator (SVC)	• Perhaps the most important FACTS device, SVCs has been used for a number of years. • Improves transmission line performance by resolving dynamic voltage problems. • Provides high performance steady-state and transient voltage control far superior to classical shunt compensation. • Dampens power swings, improves transient stability, and reduces system losses by providing optimized reactive power control.
Solid state transfer switch	• Provides undisturbed power using two independent feeders. • Mitigates power quality events. • Is available today, but because of high cost and limited experience base, has been deployed only sparingly. Broader deployment will take place as technical performance is proven, as costs drop, and as its societal value is recognized.

Power Electronic Devices	
Advanced component	**Description**
Dynamic brake	- Rapidly extracts energy from a system by inserting a shunt resistance into the network. - Adding thyristor controls to the brake permits addition of control functions, such as on-line damping of unstable oscillations. - BPA has installed such a dynamic brake on their system. - Is available today, but because of high cost and limited experience base, has been deployed only sparingly. Broader deployment will take place as technical performance is proven, as costs drop, and as its societal value is recognized.
AC/DC inverter	- Mature technology that can be further improved to meet future needs. - Provides the grid interface for a variety of distributed generation sources. - Future improvements in high-power semiconductors may make it economically viable to convert large areas of the grid to DC operation.

Table 1: Examples of power electronic devices

Superconductivity

Several DOE-sponsored cable demonstration programs are now underway at AEP/Southwire/Columbus, Ohio; National Grid/Sumitomo-SuperPower/ Albany, NY; and LIPA/Nexans-AMSC/Long Island, NY

The bulk of U.S. research and development related to superconductivity is currently supported by the Department of Energy (DOE) (2). Several projects demonstrating pre-commercial utility applications of high temperature superconducting (HTS) technology have emerged, and new projects are being developed.

National Laboratories are engaged in research aimed at investigating underlying principles of superconductivity and to address fundamental technological issues. A close working relationship between the national labs and academia ultimately benefits both organizations through the use of university expertise and facilities that, in turn, strengthen and expand the national laboratories' capabilities.

Part of the program is aimed at completing research needed for U.S. industry to scale up new superconducting-wire manufacturing processes. Innovative approaches discovered at national laboratories are being developed into commercially viable processes by public companies. Only short lengths of second-generation wire have been produced thus far, but the performance is far better than any existing wire and the cost-savings potential is significant. The goal is to enable U.S. industry to manufacture long-length wire, suitable for widespread use in industrial and commercial settings.

Examples of advanced superconducting materials and components currently being researched and developed may be found in Table 2.

Superconductivity	
Technology	**Description**
First generation (1G) wire	• Can be manufactured today. • Used in short line segments as exits from congested substations or in urban areas and as fault current limiters. • Applied as a very low impedance path to help control power flows on congested parallel lines. • Reduces pollution from electric generating facilities. • Raises electric system reliability. • Improves power delivery systems in urban areas without new rights-of-way.
HTS cable	• Transmits large quantities of power at reduced voltages and high currents. • Lower voltages reduce HVDC terminal costs by 25% to 50%. • May be competitive with UG cables employing large quantities of high-priced copper. • Can reduce urban transmission congestion or allow for more intensive urban development. • Can be manufactured today in small quantities. • Still in R&D; could have a huge impact and could, with the proper motivation, move from the laboratory to broad application in the short term.
Second generation (2G) superconducting wire	• Longer term development needed (5-10 years), with huge potential grid impact. • Can be manufactured today in small quantities. • Cost and performance of HTS devices will significantly improve. • Provides lower-cost control of flicker, voltage, and transient stability. • Prices could be 3 to 10 times lower than 1G wire and have 10 times lower losses. • Will penetrate the replacement market for large industrial motors, power plant auxiliary motor drives, and power plant generators. • Long-distance, low-impedance underground transmission of power is the ultimate goal. • 2G wire fault current limiters (FCLs) can be developed that have ten times lower losses, limit currents by a factor of three to ten, and have small footprints. • Other issues will need to be anticipated and resolved, like the changing dynamic characteristics of customer and plant auxiliary loads, and increased fault currents.

Table 2: Examples of superconducting devices

Advancements in materials are needed to accelerate development and implementation of superconductivity for the grid. As these advances occur, superconductivity will increasingly be used for short-line segment exits from congested substations, superconducting magnetic energy storage (SMES), superconducting synchronous condensers, fault current limiters (FCLs), high-efficiency motors and generators, and, ultimately, long-distance lossless transmission lines.

Generation and Storage Distributed Energy Resources

Distributed energy resources (DER) are small-scale power generation and storage technologies, typically in the range of 3 to 10,000 kW, located close to where electricity is used (e.g., a home or business) to provide an alternative to, or an enhancement of, the traditional electric power system. DER will play a large role in the modern grid. But an interface using power electronics, along with new local control and protection schemes, is needed to mate DER sources to the grid. Further development of fundamental DER energy-conversion technology is needed to lower cost and improve performance. Eventually, key technology improvements will allow remote management of multiple, diverse DER devices operating as an integrated system.

The development of advanced components, such as the low-cost power electronic interfaces needed for a variety of DER sources, combined with the associated communications, protection, and control systems, is a work in progress. DER will also profit by advances in the underlying core technologies such as the chemistry involved with distributed storage devices.

Distributed Generation Devices

Enabled by improvements in chemistry, materials, and power electronics, these new advanced components are all in various stages of development today. With sufficient industry support, they will become available in large quantities at attractive prices in the future.

A portfolio of distributed generation (DG) technologies (3) is summarized in Table 3.

Distributed Generation	
Advanced component	**Description**
Microturbine	• An emerging class of small-scale distributed power generation in the 30-400 kW size range. • Consists of a compressor, combustor, turbine, and generator. • Most microturbine units are designed for continuous-duty operation, fueled using natural gas. • A number of companies are currently field-testing demonstration units, and several commercial units are available for purchase. • Combined heat and power applications offer very high overall efficiency.
Fuel Cell	• Very low levels of NO_x and CO emissions. • Many types of fuel cells currently under development, including phosphoric acid, proton exchange membrane, molten carbonate, solid oxide, alkaline, and direct methanol. • One company currently manufacturers a 200 kW phosphoric acid fuel cell for use in commercial and industrial applications. • A number of companies are close to commercializing proton exchange membrane fuel cells, with marketplace introductions expected soon. • Cost-effective, efficient fuel reformers that can convert various fuels to hydrogen are necessary to allow increased flexibility and commercial feasibility.
Photovoltaic (PV): "Solar Panel"	• Solar panels are made up of discrete cells connected together that convert light radiation into electricity. • Produce no emissions, are reliable, and require minimal maintenance to operate. • Those deployed by NASA for space applications have efficiencies of 25% in actual use. • Currently available from a number of manufacturers for both residential and commercial applications; manufacturers continue to reduce installed costs and increase efficiency. • Applications for remote power are quite common.
Wind Turbine	• In the United States alone, 8 million mechanical wind generators have been installed. • Considered the most economically viable choice within the renewable energy portfolio. • Environmentally sound and convenient alternative. • Are currently available from many manufacturers, and improvements in installed cost and efficiency continue.

Table 3: Examples of distributed generation

Older, more mature categories of distributed generation include the reciprocating diesel engine and the reciprocating natural gas engine.

These are the most common machines for power generation, mechanical drive, or marine propulsion. While improvements in operation, environmental responsibility, and power production are still being made, these cannot truly be called advanced components.

Combustion gas turbines, which range from one MW to several hundred MW, are another older distributed generation technology that is still undergoing improvements. Here are some features of the combustion gas turbine:

- Based on jet propulsion engine technology designed specifically for stationary power generation or compression applications in the oil and gas industries.
- Relatively low installation costs, low emissions, and infrequent maintenance requirements.
- Low electric efficiency has limited turbines to primarily peaking units and combined heat and power applications.
- Co-generation distributed-generation installations are particularly advantageous when a continuous supply of steam or hot water is desired.

Table 4 compares various distributed generation technologies (*3*).

Distributed Generation: A Comparison					
Technology	**Recip Engine: Diesel**	**Recip Engine: NG**	**Microturbine**	**Combustion Gas Turbine**	**Fuel Cell**
Size	30kW - 6+MW	30kW - 6+MW	30-400kW	0.5 - 30+MW	100-3000kW
Installed Cost ($/kW)	600-1,000	700-1,200	1,200-1,700	400-900	4,000-5,000
Elec. Efficiency (LHV)	30-43%	30-42%	14-30%	21-40%	36-50%
Footprint (sqft/kW)	.22-.31	.28-.37	.15-.35	.02-.61	.9

Table 4: Comparison of distributed generation

Distributed Storage Devices

Energy storage systems employ such chemical formulations as the vanadium redox flow battery (VRB) or the sodium sulfur (NaS) battery to provide long-life systems that improve load factor (8 hours of storage or more) while enhancing power quality, and at the same time offer voltage and transient stability mitigation and frequency regulation. Advanced, low cost, high-energy density flywheel energy-storage systems with 15 to 60 minutes of storage can provide customer power during grid outages.

Table 5 describes some distributed storage devices.

Distributed Storage	
Advanced component	**Description**
NaS battery	• Consists of liquid (molten) sulfur at the positive electrode and liquid (molten) sodium at the negative electrode as active materials separated by a solid beta alumina ceramic electrolyte. • Is efficient (about 89%). • Is economic to use in combined power quality and peak shaving applications. • Has been demonstrated at over 30 sites in Japan totaling more than 20 MW with stored energy suitable for 8 hours daily peak shaving. • Combined power quality and peak shaving applications in the U.S. market are under evaluation. • Pilot installation at AEP.
Vanadium Redox Battery (VRB)	• A flow battery with external tanks containing vanadium aqueous solutions. • Can be used for peak shaving, frequency regulation, voltage and transient stability support, and customer ride-through. • Number of hours of storage can be increased by simply increasing the size of the external tanks. • Low power density of the electrolyte and the space requirements are drawbacks. • VRB flow batteries with 8 hours of storage are available in small sizes.
Ultracapacitors	• Stores energy like a battery. • Can quickly discharge the energy in seconds like a capacitor.
Superconducting Magnetic Energy Storage (SMES)	• Most commonly devoted to improving power quality. • Power is available almost instantaneously and very high power output can be provided for a brief time. • Loses the least amount of electricity in the energy storage process compared to other methods of storing energy. • Distributed SMES units have been deployed to enhance stability of a transmission loop.

Table 5: Distributed storage

Complex Systems

Various distributed energy resources can be integrated to create power supply systems with unique characteristics, as shown in Table 6.

Complex Systems Employing Advanced DER Components	
System	**Description**
Microgrid	• Small local power systems that can stand alone or be integrated with a larger conventional distribution feeder. • Includes energy storage and DG to establish a small independent control area. • Can employ various types of DG. • One design employs SmartSource™, which provides plug-and-play functionality without relying on communications. • One design employs SmartSwitch™, which provides a single interface to the power system allowing smooth transition between parallel and islanded operation. • Phased field trials at American Electric Power Company.
Premium Power park	• Employs uninterruptible power supplies, such as battery banks, ultracapacitors, or flywheel energy storage; can also employ high-speed transfer switches, DVRs and other power electronic devices, and DG. • Premium Power parks can attract high-tech industry to a region by providing the ultra-clean power needed for sensitive industrial processes.

Table 6: Complex Systems

In addition to DER, the modern grid must continue to support a wide variety of large central generation units, including fossil, hydro, wind, geothermal, and nuclear plants.

Composite Conductors

New materials are opening up new ways for advanced components to improve the performance of the grid.

For instance, composite conductors such as new high-temperature, composite transmission-cable designs will enable increased utilization of right of way (ROW), allowing a doubling of amperage limits with little change to the line support or towers.

The description of several composite conductors is found in Table 7.

Composite conductors	
Advanced Component	**Description**
Aluminum Conductor Composite Core Cable **(ACCC™ Cable)**	• Is superior to existing T&D cable in a number of key performance areas (*4*). • Offers double the current-carrying capacity when compared to most standard conductors. • Can dramatically increase system reliability by virtually eliminating problematic high-temperature cable sag. • ACCC™ cable will be as easy to install as conventional utility cable. • In operation at HV.
Aluminum Conductor Composite Reinforced Cable (ACCR)	• Can increase transmission thermal capacity 150% to 300%. • In operation at over a dozen utilities beginning in 2001.
Annealed aluminum, steel supported, trapezoid cross section conductor wire (ACSS/TW)	• Can operate at 200 C. • Carries 100% more current. • Reduces line losses at normal loads. • Can be handled like normal aluminum cable steel reinforced (ACSR) conductor wire. • In operation at HV.

Table 7: Composite conductors

Grid-Friendly Appliances

Advances in microelectronics are making possible the production of grid-friendly appliances (GFAs) that will help stabilize the grid in times of system stress. These localized controllers, installed in a wide range of home appliances, will make it possible to automatically switch home electric appliances off and on in order to modulate load during system disturbances. They may also be designed to respond to electricity pricing signals.

The addition of voltage- and/or frequency-sensing chips to a wide range of home appliances could offer substantial power system benefits. Properly conceived GFA control algorithms can impact the power grid in profound ways. Frequency-sensitive GFAs are ready now, but manufacturers need to be convinced of the value of adding them to appliances such as washing machines, dryers, refrigerators, and heating, ventilating, and air conditioning units. Government incentives, similar to the Energy Star program, would help advance this product offering,

Improved modeling of loads and power system performance is also needed to verify the potential of this new advanced component. A proliferation of grid-friendly appliances could create the ability to use distributed load itself as a major system-level control element. This would fundamentally alter electric system behavior and place more of the control actuation into the loads themselves.

FUTURE STATE

The modern grid will employ a range of advanced components that will greatly enhance the performance of transmission and distribution systems.

Power quality will be improved through new technology and by seeking an optimal balance between grid and load characteristics. Transmission capacity and reliability will be enhanced through the application and retrofitting of a variety of advanced components, many based on advanced power electronics and new types of conductors. Distribution systems will incorporate many new storage devices and sources and will employ new topologies, including microgrids.

Economical FACTS devices will make use of new low-cost power semiconductors having far greater energy-handling capacity than today's semiconductors. Distributed generation will be widely deployed and multiple units will be linked by communications to create dispatchable virtual machines. Superconductivity will be applied to fault current limiters, storage, low loss rotating machines, and lossless cables. Advanced metering and communications will enable a suite of demand response (DR) applications, including the integration of GFAs and plug-in hybrid electric vehicles (PHEVs).

New energy storage technologies will be deployed as DER and as large central plants. The mix of generation will include large central power plants having a range of characteristics (e.g., heat rates, emissions, inertia, ramp rates, etc), in addition to distributed energy resources (many of the green variety) having a different set of performance characteristics. The combination of generation types will operate in a coordinated manner so as to optimize cost, efficiency and reliability and minimize environmental impact.

THE ROLE OF POWER ELECTRONICS

Further developments in semiconductor technology will allow new advanced components, based on power electronics, to be reliably and economically applied to a variety of T&D solutions. Greater energy-handling capabilities of individual power semiconductors will lead to more economical applications.

Material developments in SiC or GaN can lead to advanced higher current and higher voltage power electronic devices than are available today. These could operate directly at line voltage and require fewer electronic switches than is possible in today's grid.

Power electronic technology will also be applied to advanced power quality devices, switching devices, transformation devices (e.g. transformers with little or no magnetic material) and frequencyconversion devices (e.g., for microturbines, fuel cells, wind turbines, or solar panels interfaced to the grid).

Farther into the future, power electronic components could employ diamonds (chemical-vapor deposition polycrystalline diamond tip or edge anodes) operating as ultra-high current, voltage, and frequency switches. FACTS, HVDC, high-speed transfer switches, and DER could then be available at much lower cost.

A bold new concept is the application of distributed FACTS, as exemplified by the distributed series impedance device. These devices might be integrated with insulator strings and shoes at transmission towers (*5*). Coupled with the transmission system to obtain operating power, they would insert inductance or capacitance in series with the transmission system to increase or decrease series impedance. This would allow for more effective control of the transmission network, reduce fault currents, and balance line voltages. These concepts and potential benefits are illustrated in Figure 2 below:

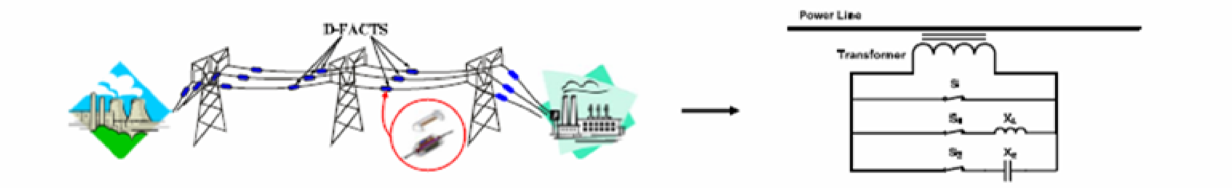


Figure 2: Concept for a distributed flow control device: Distributed series impedance (DSI) or Smart Wires device for instant power flow control. Image courtesy of IPIC at Georgia Institute of Technology.

In addition, power electronic devices could begin to replace iron and copper transformers, initially in the distribution system and eventually in the transmission system. These power electronic systems, first based on SiC devices and eventually based on diamond devices, would not only be able to control the voltage, but also be able to inject reactive power into the T&D system based on automated distributed controls, as shown in Figure 3 below:

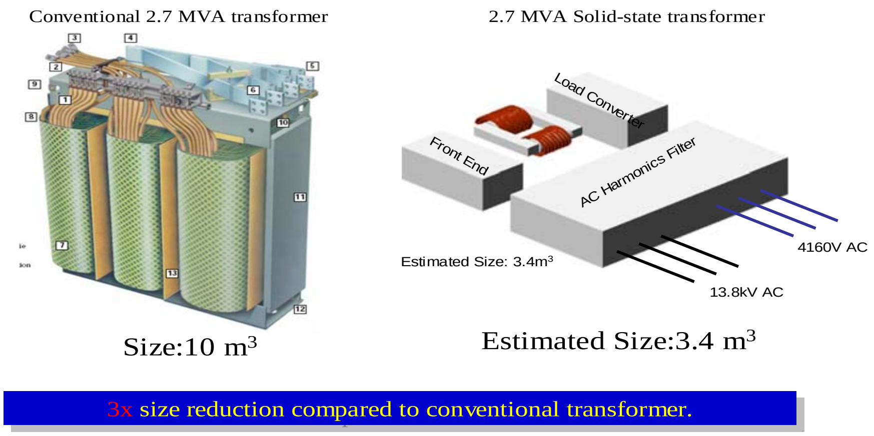


Figure 3: Future concept of solid-state power electronic transformer: Solid-state transformer (SiC based), from concepts by North Carolina State University's Semiconductor Power Electronics Center (SPEC). Image courtesy of NC State University.

THE ROLE OF SUPERCONDUCTIVITY

Commercial HTS products are beginning to reach the market. SuperVAR™ synchronous condenser is a good example. SuperVAR™ dynamic synchronous condensers help alleviate voltage problems in many applications including the following:

- Reactive compensation for T&D systems
- Steady state voltage regulation of long radial delivery systems
- Dynamic power factor correction at large industrial sites
- Flicker mitigation for sensitive power quality
- Grid stability

Figure 4 below shows the first installation of this new technology.

Figure 4: Voltage and transient stability control technology, high temperature superconducting (HTS) synchronous condenser. American Superconductor at TVA. Image is courtesy of TVA and AMSC.

It is important to note that superconducting technology will, in general, increase the severity of fault currents. This intensifies the need for higher-rated circuit breakers and HTS fault current limiters. However, second Generation (2G) wire FCLs could be developed that have ten times lower losses, limit currents by a factor of three to ten, and have small footprints.

With the commercial deployment of HTS synchronous condensers, the realization of new HTS industrial electric motors and HTS generators becomes more likely. This will impact the dynamic characteristics of loads, especially when 2G wire becomes available in 1 km lengths.

The increased efficiency from superconducting machines and cable has the potential to produce huge environmental benefits.

THE ROLE OF PLUG-IN HYBRID ELECTRIC VEHICLES

Plug-in Hybrid Electric Vehicles (PHEVs) could turn out to be the most important new electrical load in a century. The potential benefits to the grid and to the nation in general are impressive. The National Renewable Energy Laboratory concluded the following (6):

- Hybrid electric vehicles, with the capability of being recharged from the grid may provide a significant decrease in oil consumption. These “plug-in” hybrids will affect utility operations, adding additional electricity demand. Because many individual vehicles may be charged in the extended overnight period, and because the cost of wireless communications has decreased, there is a unique opportunity for utilities to directly control the charging of these vehicles at the precise times when normal electricity demand is at a minimum.
- Based on existing electricity demand and driving patterns, a 50 percent penetration of PHEVs would increase the per capita electricity demand by around 5 to 10 percent, depending on the region evaluated. While increasing total electrical energy consumption (but without requiring additional generation capacity), the optimal dispatch of the additional PHEV demand would increase loading of baseload power plants built to meet the normal demand. This also would substantially decrease the daily “cycling” of power plants, both of which would translate into lower operational costs.
- While it appears that PHEVs are much better suited for short-term ancillary services such as regulation and spinning reserve, a large fleet of PHEVs could possibly replace a moderate fraction (perhaps up to 25 percent) of conventional low-capacity factor (rarely used) generation for periods of extreme demand or system emergencies. Overall, the ability to schedule both charging and very limited discharging of PHEVs could significantly increase power system utilization.

BENEFITS OF IMPLEMENTATION

Installation of advanced components will lead to a significantly enhanced grid that provides power to meet the increasingly diverse needs of the twenty-first century.

At the transmission level, FACTS or HTS synchronous condensers will provide instantaneous support of voltage to reduce the sags that are the biggest customer power-quality problem. Fault current limiters will reduce the voltage depressions created by transmission system faults, while synchronous switching will limit transient over-voltages.

At the distribution level, high-speed transfer switches will instantly remove disturbed sources and replace them with clean, backup power supplies. FACTS (e.g., DVAR), DER, and microgrids will provide voltage support and load isolation to aid grid reliability and minimize power-quality events.

The modern grid's reliability will greatly increase due to its self-healing characteristic. Self-healing will be enabled by several complementary key technology areas:

- Very rapid and sophisticated sensing and measurements will be enabled by technologies such as the instantaneous phasor measurements of a wide-area monitoring system (WAMS).
- Advanced components (such as FACTS, HTS synchronous condensers, and distributed power-flow control devices) will give the grid the ability to respond quickly to an emergent problem by using strategies like changing flow patterns and voltage conditions.
- Decision support systems will enable a modern grid to "know" when there is a need to shed load on the distribution system. A modern grid could also immediately call for increased real and/or reactive power output from DER to support transmission needs.
- Additional reliability will result when low-cost, power-electronic interfaces for a variety of DER sources (along with the associated communications, protection, and control systems) are developed to provide built-in local control and protection.
- In addition to DER, the modern grid will continue to support a wide variety of large central generation units (fossil, hydro, wind farm, geothermal, nuclear, etc.). Advanced components will help ensure the stability and the efficiently integrated utilization of these many diverse generation sources.

In addition to more reliability, the grid will be more secure when advanced components contribute to its self-healing characteristic. The security of the grid is integrally related to its ability to heal itself. A grid that is highly diversified, with multiple sources, is all the more secure from a concerted physical or cyber attack. The modern grid will be designed with hardened integrated communications systems that are less vulnerable to such attacks than the grid that exists today. Additionally, the measurement, protection, and control systems associated with advanced components will all communicate through highly encrypted digital channels that are extremely difficult to overcome.

Grid efficiency is another characteristic that will greatly improve as advanced components maximize asset utilization and reduce electrical losses. As an example, superconducting lines and machines will produce major efficiency gains throughout the electric power system, including even the customers' loads. Flow and voltage control, as well as DER, will reduce electrical losses on the grid, DER by reducing the need to transport power over long distances. And DER that employs combined heat and power will operate much more efficiently than conventional central generation.

Advanced components will enable the grid to become more environmentally friendly. To the degree that advanced components make the grid more efficient, they make it cleaner. For instance, many DG technologies, such as solar and wind farms, fuel cells, and superconducting machines, are less polluting than conventional energy-producing methods. In addition, improved power-transfer capability means fewer lines are needed, which also lessens environmental impact. And the environmental damage associated with power outages is reduced when the grid becomes more reliable.

Another benefit of advanced components is the wide variety of ways they will foster grid economy. The following are a few specific examples:

- Advanced components improve the linkage between buyers and sellers of electric energy, and thus create a more robust market and greater access to lower-priced power.
- The proper application of FACTS devices will allow the deferral of costly major line additions
- FCLs will reduce the need to replace entire systems that are unable to handle increasing fault levels.
- DER storage will lessen expense by making the addition of peaking generation unnecessary.

Advanced components will be employed to reduce transmission congestion costs, saving billions of dollars each year. The above are but a few examples.

BARRIERS TO DEPLOYMENT

An unintended consequence of restructuring in the electric power industry has been reduced research and development related to advanced components.

Engineering-oriented power industry managers, having a long term view, created a U.S. grid that was world-class for most of the twentieth century. But today's business-oriented managers, operating in a restructured utility environment, have adopted a shorter term perspective. Incremental improvements are still sought, but the break-through technologies, such as superconducting transmission lines, that are frequently more costly have lost their appeal.

The R&D cost to create many advanced components (e.g., superconducting transmission lines, advanced power electronics, etc.) is high and private industry has been reluctant to invest in costly, long-term developments. Federal and state funds needed to augment private investment have been very limited.

Still another barrier is the lack of integration testing that demonstrates the benefits technologies that are incorporated into functional systems.

A lack of understanding of the fundamental value of a modern grid, and of the societal costs associated with an antiquated one, has created the misperception that today's grid is "good enough."

Meanwhile, the technical experience base is graying, so there are fewer and fewer advocates for the modern grid technology.

The U.S. economy will suffer in many ways if we cannot develop and employ the technologies needed for a world-class power grid.

Without the development and deployment of key technologies like advanced components, our power grid will remain at high risk for widespread blackouts, such as the one that occurred in 2003 affecting 40 million people in the United States and 10 million in Canada.

Possible Solutions

A first step toward achieving the modern grid is prioritization of advanced components' development. An understanding of the benefits of implementing these components will stimulate investment and governmental support. A consensus among all stakeholders is needed regarding the value of advanced components. So, too, is their enthusiastic and vocal support.

Regulators can be the change-agent to lead the way in grid modernization. They must act now to correct the unintended drawback that deregulation has caused. R&D must be significantly encouraged, supported, and increased in the utility sector.

SUMMARY

Achieving the modern grid is absolutely necessary to provide our country with reliable, secure, economic, and efficient power that is safe and environmentally responsible.

To do this, the modern grid requires a wide range of advanced components based on new developments in power electronics, superconductivity, chemistry, materials, and microelectronics.

For example, one important need is the development of economical FACTS devices that will employ low-cost power semiconductors having far greater energy-handling capacity than today's semiconductors. Also, it is necessary that DER be widely deployed, with multiple units being linked by communications to create dispatchable virtual machines.

Superconductivity needs to be economically applied to fault current limiters, storage, low loss rotating machines and lossless cables. And new storage technologies must be deployed for both DER and large central plants.

New kinds of electrical loads can enhance grid performance by responding to momentary problems (GFAs) and by improving load factors (PHEVs).

The mix of power generation must include large central power plants and DER. Environmental emissions will be reduced when many of the DER technologies, such as wind, fuel cells, and solar, are incorporated into the power grid.

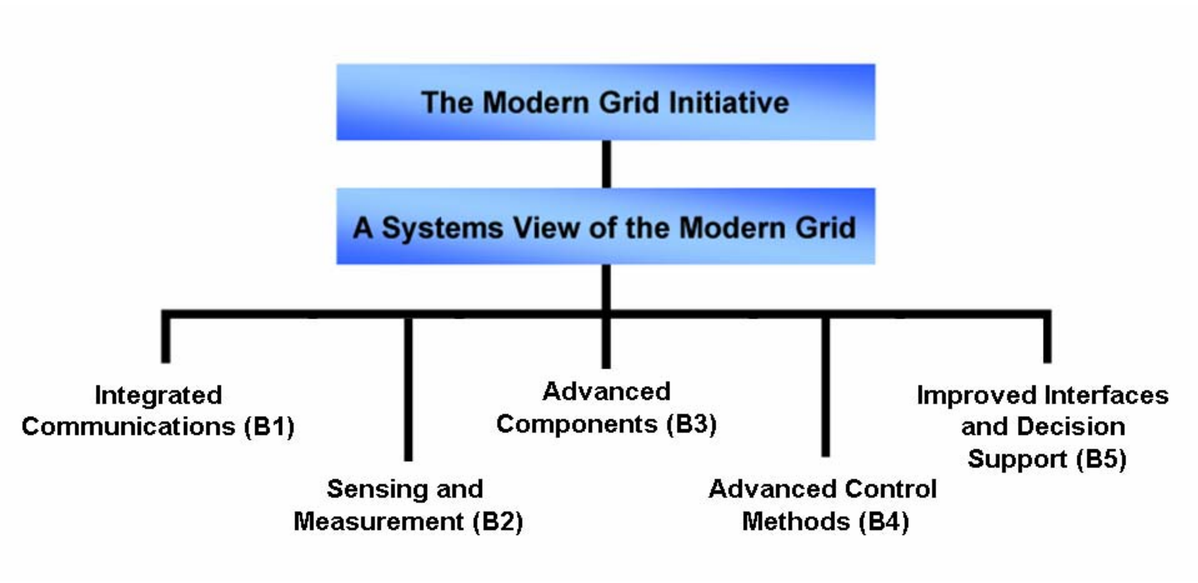
To achieve a modern grid, a combination of advanced components must operate in a coordinated manner so as to optimize efficiency and reliability and lessen environmental emissions.

All of these advanced components are necessary to build the modern grid our country must have to support the energy needs of our modern society.

For More Information

This document is part of a collection of documents prepared by the Modern Grid Initiative (MGI) team. For a high-level overview of the modern grid, see "A Systems View of the Modern Grid." For additional background on the motivating factors for the modern grid, see "The Modern Grid Initiative."

MGI has also prepared five papers that support and supplement these overviews by detailing more specifics on each of the key technology areas of the modern grid. This paper has described the third key technology area, “Advanced Components.”



These documents are available for free download from the Modern Grid web site.

The Modern Grid Initiative

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ACRONYMS

1G	First generation
2G	Second generation
AC	Alternating current
ACCC	Aluminum conductor composite core
ACCR	Aluminum conductor composite reinforced
ACSR	Aluminum cable steel reinforced
AEP	American Electric Power Co.
ACSS/TW	Annealed aluminum steel supported trapezoidal Wire
BPA	Bonneville Power Administration
DC	Direct current
DER	Distributed energy resources
DG	Distributed generation
DR	Demand response
DSI	Distributed series impedance
DSTATCOM	Dynamic static compensator
DVAR	Dynamic VAr
ETO	Emitter turn off
FACTS	Flexible alternating current transmission system
FCL	Fault current limiter
GaN	gallium-nitrogen
GFA	Grid- friendly appliances
HTS	High temperature superconducting
HVDC	High voltage direct current
IGBT	Insulated gate bipolar transistor
IGCT	Insulated gate commutated transistor
MW	Megawatt
NaS	Sodium sulphur
NYPA	New York Power Authority
PHEV	Plug-in hybrid electric vehicles
PV	Photovoltaic
R&D	Research and development

ROW	Right of way
SiC	Silicon-carbon
SMES	Superconducting magnetic energy storage
STATCOM	Static compensator
SVC	Static VAr compensators
T&D	Transmission and distribution
UG	Underground
UPFC	Unified power flow controller
VAr	Volt-amperes reactive
VRB	Vanadium redox battery
WAMS	Wide area monitoring system
WBG	Wide band gap