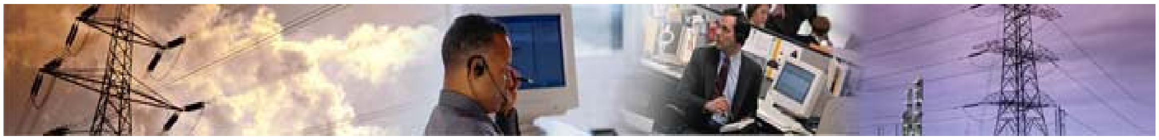

Appendix A5:
A Systems View of the Modern Grid

ACCOMMODATES ALL GENERATION AND STORAGE OPTIONS

Conducted by the National Energy Technology Laboratory
for the U.S. Department of Energy
Office of Electricity Delivery and Energy Reliability
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NETL

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The systems view of the modern grid features seven principal characteristics of a modern grid. (See Figure 1.) Accommodating alternatives to generating and storing electrical power is one of those characteristics. Our economy depends too much on large, centralized generation facilities and not enough on distributed energy resources.

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

This document provides detail on one of those important qualities: The ability to safely and seamlessly accommodate a wide variety of generation, from massive centralized plants to small solar panels and everything in between.

The modern grid must accommodate not only large, centralized power plants, but also the growing array of distributed energy resources (DER). Today, grid-connected distributed generation supplies only 3% of our total. Going forward, DER will increase rapidly all along the value chain, from suppliers to marketers to customers. Those distributed resources will be diverse and widespread, including renewables, distributed generation and energy storage. Our goal should be widespread adoption of DER, similar to what has occurred with computers, cell phones, and the Internet. (See Figure 2.)

Coping with that diversity will require a host of new and improved functions. Achieving a modern grid will require additional developments in real-time pricing, in smart sensors and controls, in a broadly accepted communications platform, and in advanced tools for planning and operation. It will also require clear standards for interconnection, performance and metrics.

Barriers exist to accommodating a wide variety of generation. Perhaps the biggest constraint is the slow development of the new functions described above. In addition, the interaction of DER with different distribution networks is not well understood. The total cost of DER is still too high, and consumers have little motivation to invest, limiting deployment to the electric industry itself. Because stakeholders have conflicting agendas – and because nobody wants to bear the costs of the "societal" benefits – vitally important projects are not being funded.

Integrating multiple generation alternatives will provide significant benefits. The result will be a more reliable, secure, efficient power grid. That grid will also be safer, less expensive and friendlier to the environment.

There is a path forward. Accelerating the deployment of DER – and the ability of the modern grid to accommodate DER and all other kinds of generation – will require a clear, consistent vision with buy-in from all stakeholder groups. It will need greater research and development, financial incentives to customers and utilities, and stimulation of customer demand. Regional transmission operators and utilities should explore DER as a solution to transmission congestion. Regional pilot programs to demonstrate the value of DER are also needed to bring increased visibility to these important resources.

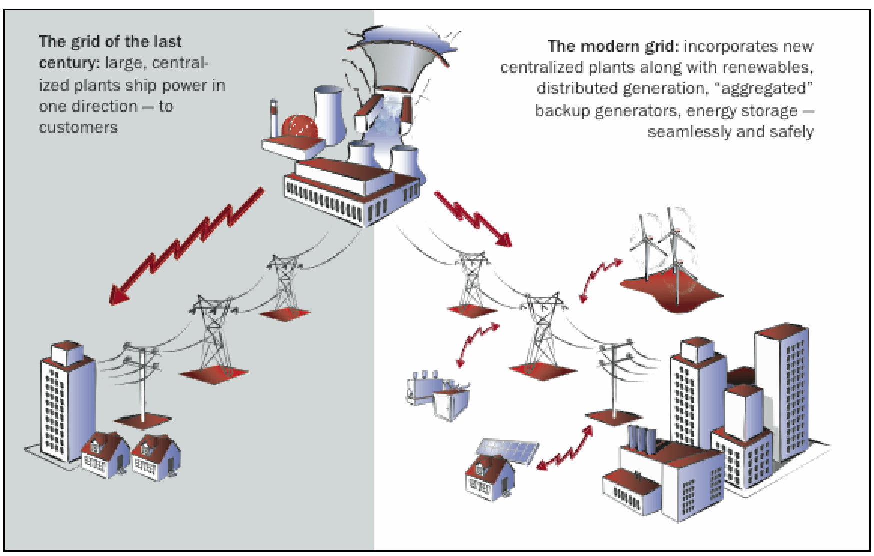


Figure 2: The modern grid accommodates all generation and storage options

This document covers:

- The current state and likely future of generation alternatives.
- The requirements for accommodating diverse generation sources (and the gap between what we have and what we need).
- The barriers to meeting those requirements.
- The benefits of success.
- The recommendations for accelerating adoption of this important characteristic of the modern grid.

CURRENT AND FUTURE STATES

Before we discuss *how* to support a wide variety of generation options, we need to understand where we are today and what kinds of options will be accessible tomorrow. This section explores the current state and the probable future state of generation.

CURRENT STATE

A substantial gap exists between existing and desired amounts of DER, particularly in the renewables category. Most of our electricity comes from centralized plants. Of the distributed generation we do have, most is "dirty" (from internal combustion engines) and disconnected from the grid. The U.S. is dominated by big, centralized generating facilities. Large generators (coal, nuclear, and hydro) made up over 75% of net generation in 2004. (See Figure 3.)

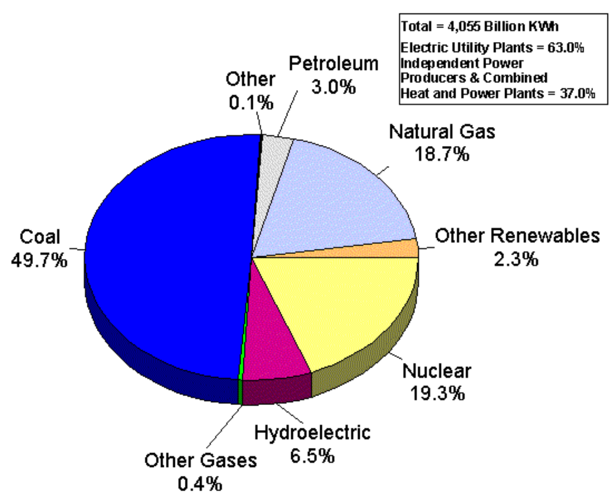


Figure 3: U.S. electric generation fuel diversity (Energy Information Administration, Form EIA-860, "Electric Power Annual" 2006 www.eia.doe.gov/cneaf/electricity/epa/figes1.html)

Small, widely dispersed plants account for an estimated 234GW of distributed generation (DG). Small reciprocating engines, used to supply emergency or standby power, account for about 81% of that total. Combined heat and power (CHP) is second at 9%. Combustion turbines are third with 7%. However, very little of that DG is connected to the grid – only 30GW or just over 3% of our 953GW total.

FUTURE STATE

The future offers several growth pathways for DER, depending on how technologies and markets evolve. A modernized grid should be prepared for five likely scenarios, itemized below.

1. DER will increase dramatically. The modern grid must expect and enable a substantial increase in new energy sources. California's Renewable Portfolio Standard (RPS) program requires investor-owned utilities to provide 20% of their electricity from renewable sources by 2010, and 33% by 2020. DER is likely to grow rapidly because of cost, regulations, environment and speed to market.

2. DER will be everywhere. Deployment will occur along the entire value chain. Suppliers will install it. Power marketers will embrace it. And all type of customers – commercial, industrial, residential -- will adopt it. The goal should be to expect and enable the same widespread deployment that occurred with personal computers and cell phones.

3. DER will be grid-connected. Standalone generation will continue to be common. But in the future, much more DER will be connected to the grid at many different points – at transmission voltages, at distribution voltages, and at AC and DC networks and micro-grids.

4. DER will be aggregated. Both the sources of power and the users of that power will often be aggregated. For instance, wind and solar units may be aggregated into energy "farms" and scattered backup generators into "peaking plants."

5. DER will be diverse. DER will not be dominated by any one size or type of generation. Instead, it will include a wider variety, from those already available to those not yet invented and popularized.

The diversity of distributed energy resources will include sources with a relatively small capacity such as photovoltaic (PV), wind, fuel cells, plug-in hybrid vehicles and energy storage. These devices will typically be connected to low voltage distribution lines or through a DC micro-grid. Their benefits and affordability will lead to a significant increase in the deployment of DER by consumers. In fact, consumers may represent the largest market well into the next decade as they use distributed generation to save money and improve reliability.

But that diversity will include large plants, too. Big power customers and marketers will invest in combined heat and power (CHP) and non-utility generation facilities. Large combustion turbines will be built at a rate consistent with fuel costs and will be located closer to load centers than conventional, centralized power stations.

As we now turn our attention to what is required to reach our DER goals, it is important to remember that the modern grid must also accommodate new centralized plants. We will need conventional, centralized power stations -- coal, oil, gas, nuclear – to meet the increase in demand.

REQUIREMENTS

Accommodating a variety of generation options will require a host of new or improved grid functions. This section discusses the importance of generation alternatives and the most essential functions needed to implement those alternatives.

THE IMPORTANCE OF GENERATION ALTERNATIVES

It is crucial that the United States move away from its current over-reliance on big, centralized generation. Our electric system must accommodate a wider variety of options, often lumped together as *distributed energy resources (DER*). The main options include:

- **Distributed generation (DG)** – small, widely dispersed plants
- **Renewables** – wind, solar, biomass, etc.
- **Energy storage** – in essence, giant “batteries” and “capacitors”
- **Demand response (DR)** – decreasing demand instead of increasing supply in response to peak loads,

Renewables such as wind and solar can be either distributed or centralized—from individual, isolated wind turbines, or centralized giant wind farms.

DER complements rather than displaces other generation. The 21st-century power system will need a diverse portfolio of generation options. Table 1 maps DER technologies to market applications.

Technology	End user	Grid support	Energy supply
	CHP Premium power Backup power Peak shaving	Asset management Reliability Power quality	In-city generation Renewable
Internal combustion engine	✓	✓	
Combustion turbine	✓	✓	✓
Microturbine	✓		
Fuel cell	✓		
Photovoltaic	✓		✓
Wind	✓	✓	✓
Energy storage	✓	✓	✓
Biomass and waste	✓		✓

Table 1– DER Options and Market Applications

Figure 4: Renewable generation sources are an important option: The modern grid must accommodate electricity from renewable sources such as wind, solar, and biomass.

DER offers advantages that accomplish many of the key success factors of the modern grid. DER increases our safety factors. For instance, allowing different plant types and fuel types makes the modern grid more resilient because a single failure or unavailability of a specific fuel type will not affect all plants, so there is no common impact to many. And decentralizing generation increases geographical dispersion.

DER improves the ability to manage the system. For instance, diversifying sizes provides flexibility in operations, while diversifying startup (ramp) rates improves response times. Energy storage devices improve power quality and reliability.

On top of all that, DER can save money. It is often faster and easier to install DER at the point of pain rather than siting, permitting, and financing a giant plant and then transmitting the power long distances. This speed and “right-size, right-place” advantage can translate to millions of dollars in reduced risk, lowered interest costs and faster solutions to costly problems. What’s more, accommodating renewables and other low-emission sources reduces environmental impact.

ESSENTIAL FUNCTIONS

Real-time pricing

When gasoline prices rise significantly, consumers get very clear “price signals” posted on signs outside the filling station. In response, they may look for alternatives, such as conservation, ethanol-based gasoline and fuel-efficient vehicles. But residential electric customers are not billed on a real-time basis. They receive a monthly bill that charges the same amount whether the electricity was used at expensive (peak) times or low-cost times. Until electric customers get price signals, they will not be motivated to pursue DER.

Tariff features are usually allowed and approved by Public Utility Commissions (PUC), so those entities must re-calculate rate designs with price as a function of time. Then technologies need to get the price signals to consumers, so they can make a decision.

Providing those signals requires smart meters, information gateways, and technologies that allow transmission and distribution operators to send pricing information. The real-time pricing information will tell suppliers, marketers, DER vendors and consumers when it makes sense to buy more DER. That investment will in turn spur the development of next-generation DER devices, making them even more cost effective.

Smart sensors and controls

Integrating DER into the system requires advances in the research and commercialization of smart sensors, protective relays and control devices. Lower cost sensors and controls will reduce DER installation costs, ensure stable operation of interconnected DER units and safeguard line crews and the public during maintenance and restoration. These devices will be needed even more as autonomous operations increase.

On the customer side of the meter, we need energy-management systems to monitor and control DER operations and demand-response requests from the utility.

Communications infrastructure

We need a standard, ubiquitous, integrated communications platform to enable all power system components to intercommunicate. Smart sensors and controls must communicate, but today's grid lacks communications integration and standardization. In most cases, communication does not yet reach to the consumer level. For system operators to integrate new generation sources, communication systems must be able to handle energy price signals and commands.

The lack of a standard platform causes hesitation. Buyers fear their investment will be stranded by technology change (as happened with beta versus VHS standards in the video tape industry). To prevent this, the communications platform of the future must have an open architecture acceptable to vendors, consumers and utilities. Such a platform will reduce the concern for stranded investments and will stimulate DER deployment.

Controls and tools for operation and planning

The modern grid will incorporate generation sources that are smaller, decentralized and often intermittent. But today's operating models cannot reliably operate this new configuration. We require several new tools and technologies:

- **New operating models and algorithms** to address the transient and steady-state behavior of the modern grid, and the integration of large amounts of DER.
- **Improved operator visualization techniques and new training methodologies** to enable system operators (both distribution and transmission) to work together to manage systems in both routine and emergency operations.
- **Advanced simulation tools** that can provide a more complete understanding of grid behavior, especially where a large number of diverse DER units are deployed. These tools are also needed to assist system planners in designing reliable power systems in this new environment.

- **Methods for resolving the unique maintenance and operational challenges** created by DER, demand response, and other new generation sources.
- **Advanced system-planning tools** that assess the benefits (and consider the uniqueness) of DER to locate optimal sites for power stations.

Interconnection codes and standards

Interconnection and operation codes and standards need to be more quickly adopted across the industry to support DER implementation. Efforts are underway to develop fair and uniform interconnection standards at the federal level and in individual states (California, Michigan, Minnesota, New York, Texas, Wisconsin and others).

The development of these standards will enable DER to be easily integrated with the modern grid—called "plug and play"—to connect any power generation into the grid and communicate fully.

Performance standards

Performance standards and metrics must also be developed. We must ensure that DER owners continuously meet their obligations to grid operators. Regulatory groups should perform periodic audits and enforce compliance when needed. Each owner should perform self-assessments. (For instance, does the unit follow dispatch instructions within tolerances?)

Metrics

Key metrics need to be developed and promulgated to provide the transparency needed to most effectively support the safe operation of the modern grid. Some areas where metrics might be established include:

- DER percentage of system-wide capacity, energy, and ancillary services
- Improvements in system and customer reliability
- Improvements in power quality
- Improvements in transmission congestion
- Energy prices, with and without congestion
- Capital investments and deferred investments
- Reduction in emissions and other environmental impacts
- Reduction in system losses

Other

The new generating sources of DER must be able to do the following:

- Auto start, load, and shut down in response to price signals and commands from system operators.
- Represent a significant amount of capacity, energy and voltage support on an aggregated, system-wide basis.

- Integrate safely and reliably with legacy distribution topologies (e.g., long radial feeders) and operations.

BARRIERS

Although DER adoption is occurring today, significant barriers remain to meeting the requirements of the previous section and proceeding to full-scale deployment.

To achieve the level needed to support modern grid operations, DER must occur at three levels: 1) electric system, 2) marketer and 3) customer level (residential, commercial, and industrial). The goal should be widespread adoption similar to what has occurred with computers, cell phones, and the Internet.

Several constraints prevent this level of deployment. Prominent among these are the slow development of the elements discussed earlier in the "Requirements" section. In addition, several other factors are holding DER back:

- **Distribution system behavior is not well understood.** We need to further study how various distribution systems interact when DER of many types and designs are broadly deployed (particularly their behavior during upset conditions).
- **Total cost of ownership is high.** The lifetime cost is too high for existing DER devices to compete with traditional alternatives (investment, operation, maintenance, fuel, etc.). Advances in R&D and commercialization are needed to make it more competitive with conventional generation. Already over 225GW of backup generation currently exists on consumer premises. However very little of this capacity is connected to the grid and dispatched by system operators because of environmental and cost considerations.
- **Consumers are not motivated to invest**. Getting varied generation options depends on motivating marketers and residential, commercial and industrial consumers to invest in DER. Until this occurs, DER investment will primarily be funded by the electric industry, limiting its deployment.
- **Conflicting agendas exist among stakeholders.** For example, deployment of DER by consumers negatively affects utility revenues. Societal benefits desired by government are normally not considered in the business plans of marketers and utilities. As a result, some projects are not being funded. They are often the very projects most important for achieving the modern grid.

BENEFITS

As we overcome the barriers to the modern grid, the seamless integration of diverse generation and storage options will deliver substantial benefits.

RELIABILITY

Combining power generation and storage options with a modern grid's advanced communication and control systems results in better reliability and power quality:

- Reduces dependency on the transmission system by strengthening the distribution system.
- Increases operational flexibility during routine, emergency and restoration activities.
- Improves power quality during times of system stress (i.e., peak load, storms, etc.) and reduces system restoration time following major events.
- Reduces transmission losses and congestion by locating generation closer to loads.
- Increases "ride-through" capability and momentary voltage support.
- Reduces the chances for a common mode failure to affect overall operation of the entire grid.

Improvements such as these put us on the road to a "self-healing" grid. In response to signals from system operators and smart sensors, DER will respond in real time with preventive and corrective actions so that reliability issues are avoided or at least mitigated.

SECURITY

The ability of the modern grid to accommodate a wide variety of options can reduce its vulnerability to security attacks and improve its security during major events. Some specific security enhancing features include:

- Decentralization to the distribution level reduces the grid's vulnerability to a single attack.
- Large quantities of smaller DER, coupled with smaller quantities of large centralized generation, reduce the impact of a unit's failure on overall grid operation.
- Diversity in DER gives operators more choices in response to a security emergency.
- Diversity in a geographic location provides alternate means to restore the grid following a major event.
- Diversity of fuels at central generating stations (coal, oil, gas, nuclear, hydro) coupled with diversity of fuels at decentralized

DER (wind, solar, gas, hydrogen for fuel cells, etc.) increases the probability that adequate fuel supplies will be available.

Economic

Accommodating a variety of generation and storage options adds to the modern grid's economic advantages:

- Eliminates or defers some large capital investments in centralized generating plants, substations, transmission and distribution lines, reducing overall costs by tens of billions of dollars over a 20-year period. *[Pacific Northwest National Laboratory, 2003]*
- Enables consumers to participate in the electricity market (and partially fund new generation).
- Reduces peak demand, transmission congestion and peak prices.
- Increases the grid's robustness and efficiency, leading to cost savings and eventual lower rates.
- Encourages retail electricity markets (capacity, energy, ancillary services) and, potentially, emissions markets.

Efficiency

The modern grid is made more efficient by accommodating many generation alternatives:

- Increases options for system planners to address future demand issues.
- Increases options for system operators to improve the utilization of grid assets.
- Improves asset utilization since plants located near load centers reduce transmission losses.

Environmental Quality

Accommodating generation alternatives is environmentally friendly:

- Encourages the deployment of smaller DER sources including those based on clean technology.
- Encourages greater use of hydro, solar, and nuclear power that produce zero emissions.
- Reduces the need for new centralized generating stations and transmission lines.

Safety

Finally, the modern grid improves safety, protecting workers and the public. It mitigates the hazards of interconnecting large numbers of diverse generating sources and energy storage devices.

RECOMMENDATIONS

Considering the barriers to meeting modern grid requirements and the benefits to be attained in overcoming these barriers, what are some of the steps we can take right now?

Table 2– Recommended Steps
Establish a clear vision
Increase R&D
Generate financial incentives
Expand customer side options
Explore DER as a congestion solution
Add demonstration programs

Specific actions are needed to rapidly accelerate deployment of generation options, including:

- **Establish a clear vision:** Stakeholders need a clear, consistent vision for the modern grid that identifies the role of generation, DER and DR. Then research, policies, statutes and reforms may be put in place that endorse this vision, remove barriers and align regulations with the goal of achieving the modern grid.
- **Increase R&D.** Additional research, development, and standards are needed to realize the elements cited in the "Requirements" section.
- **Generate financial incentives:** National energy legislation and regulations are needed to provide financial incentives for investing in DER. These programs should consider total societal benefits. Investment incentives should be made available to consumers. And financial relief should be given to corporations who make generation investments to help offset possible stranded investments.
- **Expand options for customers:** Although great strides have been made in DER research and commercialization, much remains to be done. Stimulation for further improvements should come from the customer side. That is, the value proposition for the consumers and marketers needs to be real and needs to depend on price signals (or perhaps legislation). For example, fuel cells for the home and business, energy storage devices, and hydrogen fuel technologies are expected to be components in the future DER portfolio.
- **Explore DER as a congestion solution.** Regional transmission operators (RTOs) need to put a higher priority on the use of DER as a solution to transmission line congestion.
- **Add demonstration programs.** State-level and regional demonstrations are needed to prove the value and uses of DER, coupled with innovations in grid design and automation. These demonstrations would establish a baseline to encourage follow-on investments in DER-enabled grid infrastructure.

SUMMARY

The ability to accommodate a wide variety of generation options is essential to realize the full promise of a modern grid. Generation will increasingly include renewables and distributed generation, alongside energy storage and other "non-traditional" sources.

Coping with that diversity will require a wide range of new and improved functions, including real-time pricing, smart sensors, integrated communications, advanced decision support tools and more.

If we successfully integrate large and small generation sources, then we will gain a grid that is more reliable, secure, safe, efficient and environmentally friendly. At the same time, it will cost less to operate and maintain.

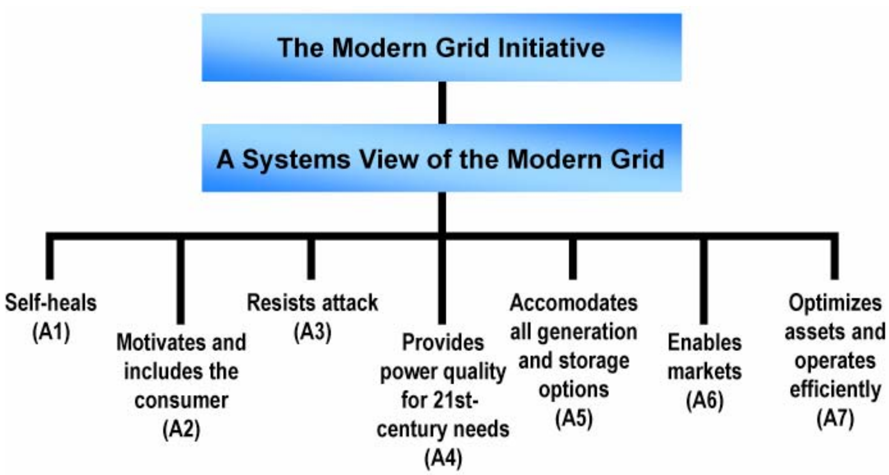
Barriers exist that may slow our progress. Our understanding of DER and its interactions is still limited, and prices remain high. Development is slow and haphazard. Important projects remain unfunded.

Despite these challenges, there is a path forward.

The Modern Grid Initiative is working with a wide range of stakeholders. The MGI objectives are to:

- Further define the vision of a grid that accommodates many different generation sources.
- Pinpoint the research and technology gaps.
- Better understand how DER fits into the larger, integrated whole.

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." Seven appendices support and supplement these overviews by detailing more specifics on each of the principal characteristics of the modern grid. This paper describes the fifth principal characteristic: "Accommodates all Generation and Storage Options."

Documents are available for free download from the Modern Grid Web site.

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