

*Distributed Generation:
System Interfaces*

AN ARTHUR D. LITTLE WHITE PAPER

ARTHUR D. LITTLE

For more than a century, Arthur D. Little has been a leader in the consulting industry. Founded in 1886 by Arthur Dehon Little, it is the world's first consulting firm. Today, it still is one of the world's premier consulting firms, with over 3,500 staff members based in 51 offices and laboratories around the globe.

Arthur D. Little has been the world's leading consultant to the energy industry since the mid-1960s. We provide consulting services to the full gamut of industry players—major, independent, and national oil and gas companies; public and private utilities; independent power producers; government institutions; suppliers and contractors, and financial institutions and funding agencies. Bringing to all these assignments tailored, multi-disciplinary case teams, Arthur D. Little provides a range of services in strategy development, organizational design and implementation, business-process redesign, technology and product innovation, and environmental, health, and safety consulting.

DISCLAIMER

Funding for this white paper was provided to Arthur D. Little, Inc., by the sponsoring organizations for an objective analysis and discussion of important issues related to the use of distributed generation. This white paper is intended for general information and not as an endorsement of any product, process, or point of view.

Executive Summary	iii
Preface	vi
I. DG Background	1
<i>What is DG?</i>	1
<i>Why is DG Emerging Today?</i>	1
<i>How Much DG is Installed Today?</i>	2
II. Distributed Generation Interfaces Today	3
<i>Electrical Interface?</i>	4
<i>Why is Grid Interconnection Important?</i>	5
III. Interconnecting DG Today	8
<i>Technical</i>	8
<i>Process</i>	11
<i>Contract (Interconnection Agreement)</i>	15
<i>Possible Solutions</i>	17
IV. The Future of Distributed Generation Interfaces	18
V. Conclusion	21
Appendix	22

Executive Summary

This white paper is one in a series of discussion documents designed to help regulators, legislators, and other interested parties better understand and evaluate distributed generation (DG). This paper examines the ways in which DG interfaces with today's energy infrastructure, with a particular focus on the electrical interface and DG interconnection with the utility grid. It also explores how these interfaces might change over time as DG technology and the electricity industry evolve.

DG is defined as the integrated or stand-alone use of small, modular electric generation close to the point of consumption. It differs fundamentally from the traditional model of central generation and delivery insofar as it can be located near end-users within an industrial area, inside a building, or in a community. The downstream location of DG in the power-distribution network provides benefits for both customers and the electric-distribution system. The small size and the modularity of DG support a potentially broad range of customer- and grid-sited applications where central plants would prove impractical. Three independent trends—utility industry restructuring, increasing system capacity needs, and technology advancements—are concurrently laying the groundwork for the possible widespread adoption of DG.

Arthur D. Little estimates that there are over 60,000 MW of DG installed in North America in the form of reciprocating engines and gas turbines, greater than the total installed capacity in California. Little of the existing energy infrastructure, however, has extensive interface with DG.

DG Interface

Interfaces are the point of interaction between DG and the energy infrastructure. Today, these interfaces are generally physical but in some instances can include a market dimension as well. The physical interfaces include a DG unit's interaction with the fuel and electrical infrastructure. Some forms of DG will involve a communications interface with a central entity that controls and/or monitors the DG system. Physical interfaces are mainly concerned with issues such as safety, protocols, system impacts, reliability, standards, and metering. The market interface covers how the DG unit or its owner interacts or competes with other suppliers in the marketplace and encompasses dispatch, tariffs, pricing signals, response, and business and operational decisions.

The electric power system interface is the means by which the DG unit electrically connects to the power system outside the facility in which the unit is installed. Depending on the application and operation of the DG unit, this interface can represent a complex parallel interconnection, or can be non-existent if the DG unit is operated in isolation. The complexity of the interface increases with the level of interaction required between the DG unit/owner and the electrical grid/distribution company.

Interfaces are the point of interaction between DG and the energy infrastructure. Today, these interfaces are generally physical but in some instances can include a market dimension as well.

The central DG interconnection question is whether existing requirements can be modified to make them more efficient, transparent, and standardized while maintaining the grid's high level of reliability and safety.

Grid interconnection is the most complex electrical interface and the source of many of the issues involving DG. The term “interconnection” is often used synonymously with the terms “synchronized operation” or “parallel operation”. In this configuration, the DG unit is connected to the electric grid system while it generates electricity.

DG Interconnection Issues

Much of the discussion and debate surrounding DG interconnection has centered on technical issues. However, there are two elements of interconnection that merit equal consideration—process and contractual issues. The central question in the technical area is whether standards can be developed that will allow for a cost effective interconnection solution, that will not jeopardize the safety and reliability of the electric power system. In addition, new technical requirements must be developed that address the emerging needs of DG for dispatch, metering, communication and control standards.

Another key interconnection issue is to develop a process that is transparent to the customer and efficient without unduly burdening distributed generators or distribution companies. Creating efficiency and streamlining existing processes while maintaining safety and reliability, especially for the smaller size generators, will be formidable tasks. The main issues on interconnection contracts are the complexity and the appropriateness of standard contract requirements to DG. An interconnection contract between a DG owner and a utility is similar to a contract between a central power facility and a utility in many respects. Many of these contracts are lengthy and complicated. While developers concede that such contracts are suitable for a 200 MW facility, there are many requirements included in the standard contracts that are not appropriate for a 200 kW facility.

Conclusions

The central DG interconnection question is whether existing requirements can be modified to make them more efficient, transparent, and standardized while maintaining the grid's high level of reliability and safety. The challenge for regulators and legislators will be to balance the tradeoffs in resolving these very complex technical and business issues in a manner that will be fair for all parties. While there may not be clear-cut solutions that would fully satisfy both utilities and DG owners, there are two main courses for resolution; standardization and third-party participation. A national (or even statewide) standard for technical requirements, process, and contracts would be valuable in resolving some of these issues. There could be little doubt that the involvement of all stakeholders is critical to resolving these issues in a manner that is acceptable to all. Third party entities (separate from customers, developers, and utilities) could play a role in both issue resolution and implementation.

In the future, the communications and market interfaces will undergo the most dramatic change. The communications interface may require the development of systems and appropriate standards and protocols to allow DG to respond to complex price signals and/or otherwise participate in power markets. To realize the full potential and maximize the benefits of DG, the market interfaces will need to be modified as well through expanded tariffs, expanded access to markets, or the creation of distribution-level power markets.

If these problems are not solved, DG may become another interesting, but impractical technology.

DG promises to significantly alter the design and operation of the power delivery system and the nature of the electric utility industry. However, before this can happen, several things must occur with respect to providing the reliable and cost effective DG interfaces. If these problems are not solved, DG may become another interesting, but impractical technology. If solved, DG has the potential to become a key part of the restructuring of the electric utility industry.

Preface

This white paper is one in a series of discussion documents designed to help regulators, legislators, and other interested parties better understand and evaluate issues surrounding distributed generation (DG). This paper examines the ways in which DG interfaces with today's energy infrastructure, with a particular focus on the electrical interface and DG interconnection with the utility grid. It identifies key issues surrounding DG interconnection and possible solutions to current obstacles. This white paper examines how these interfaces might change over time as DG technology and the electricity industry evolve.

I. Distributed Generation (DG) Background

What is DG?

DG is defined as the integrated or stand-alone use of small, modular electric generation close to the point of consumption. It differs fundamentally from the traditional model of central generation and delivery insofar as it can be located near end-users-within an industrial area, inside a building, or in a community. The downstream location of DG in the power-distribution network provides benefits for both customers and the electric-distribution system. The small size and the modularity of DG support a potentially broad range of customer- and grid-sited applications where central plants would prove impractical.

DG is defined as the integrated or stand-alone use of small, modular electric generation close to the point of consumption.

Why is DG emerging today?

DG is emerging as a promising generating technology for a number of reasons. Three independent trends-utility industry restructuring, increasing system capacity needs, and technology advancements-are concurrently laying the groundwork for the possible widespread adoption of distributed generation (DG).

Policymakers at the federal, state, and local level have been seeking to decrease the cost of electricity to consumers through a dramatic restructuring of the electric power industry. Although the ultimate outcome of restructuring is not yet clear, certain events are occurring that bode well for DG. The opening of retail markets has resulted in a large number of competitors offering new products and services that include DG. Utilities that are regulated under performance-based ratemaking could benefit by deploying DG to improve asset utilization. Under competition, price signals will provide economic incentives for DG as electricity-related services are unbundled and sophisticated market mechanisms such as real-time pricing become commonplace.

At the same time, regulators and policymakers are faced with serious challenges surrounding anticipated system capacity deficits in many regions. Long-term growth in electrical demand is now expected to be higher than earlier projections indicated. This is problematic since planned new generating capacity is simply not keeping pace and few bulk transmission additions are currently anticipated. Part of the problem is that industry restructuring presumes market-driven generation investments rather than centrally integrated utility planning. In this interim era before markets are fully deregulated, many owners delayed investment in large construction projects. Many industry experts anticipate capacity shortfalls and delays in bringing new generating capacity on-line in the near term.

Traditional supply-side approaches that employ the central plant model to increase local or regional generating capacity can require many years for design, approval, and construction and in some cases require large investments in the transmission and distribution

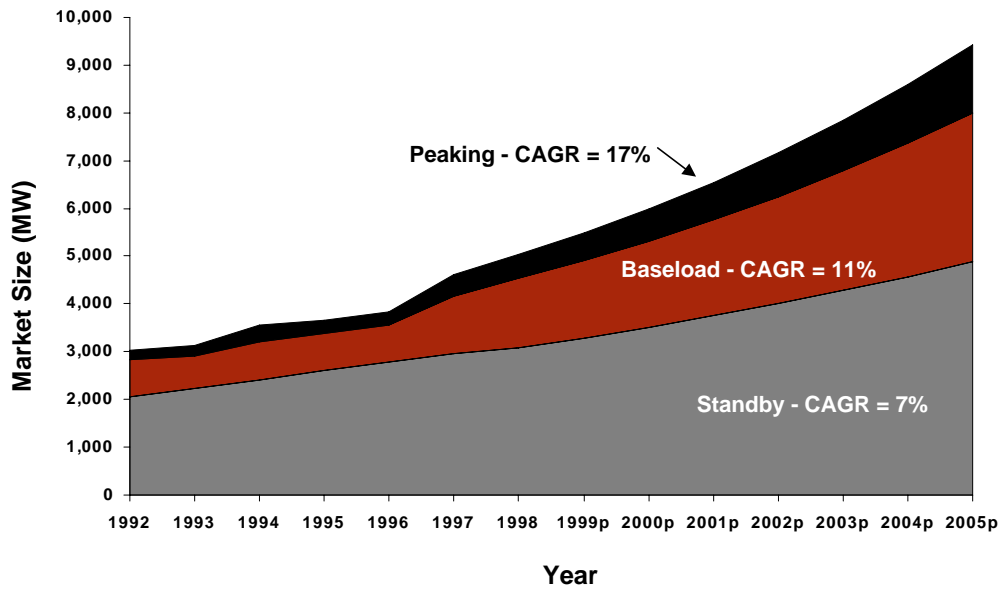
Arthur D. Little estimates that there are over 60,000 MW of reciprocating engines and small gas turbines (<20 MW) installed in North America, greater than the total installed capacity in California.

system. Uncertainty regarding future regulatory and market conditions has delayed action. In this environment, DG can be a viable generating option to meet expected load growth and relieve transmission constraints. The most timely and economical sources of new power may indeed be smaller, strategically located facilities that avoid transmission and distribution infrastructure costs while offering unique benefits that grid power alone cannot provide.

How much DG is installed today?

Since DG applications will evolve as the electric industry moves through the process of divestiture and deregulation, typical forms and uses of DG look different today than they will in the future. It is clear that since the early 1990s, reciprocating engines and gas turbines have been rapidly building a presence in the electric utility industry (see Figure 1). These technologies have been used for decades by both utilities and end-use customers to provide back-up power. This DG application continues to grow steadily at 7% per year. Other DG applications (particularly to meet baseload and peaking requirements) are growing even more rapidly at 11% and 17% per year, respectively. In addition, some of the units that were originally installed to provide backup power can be reconfigured to serve peak shaving applications. Arthur D. Little estimates that there are over 60,000 MW of reciprocating engines and small gas turbines (<20 MW) installed in North America, greater than the total installed capacity in California. Currently, little of this DG has extensive interface with the existing energy infrastructure.

Figure 1: North American Reciprocating Engine and Gas Turbine Sales (<20MW)

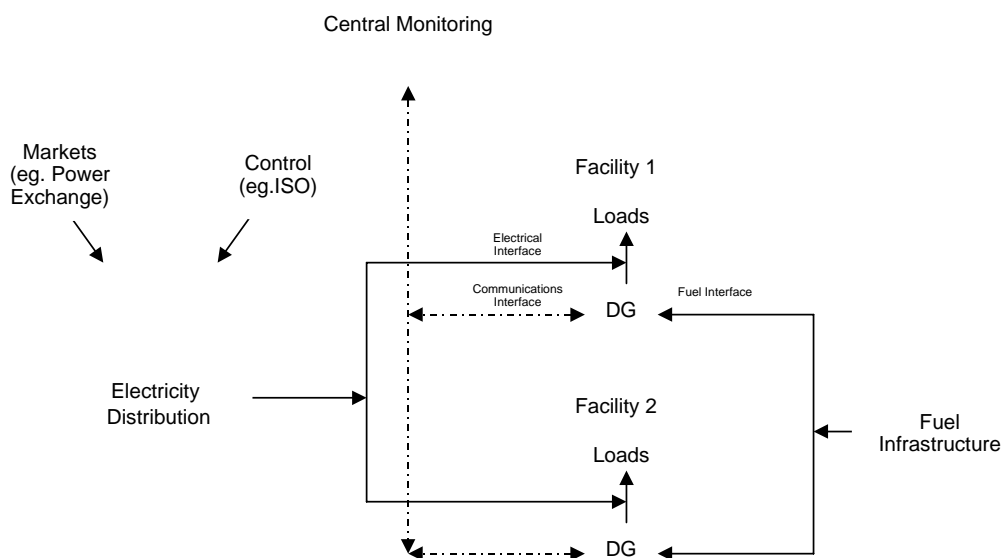


Source: Power Systems Research, Diesel and Gas Turbine Worldwide and Arthur D. Little Analysis
CAGR = Combined Annual Growth Rate

II. Distributed Generation Interfaces Today

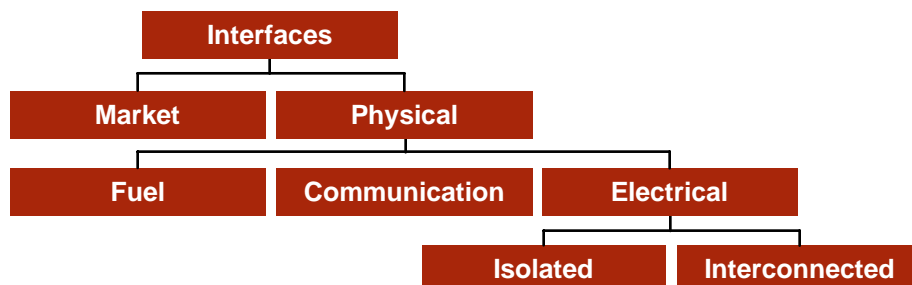
Interfaces are the point of interaction between DG and the energy infrastructure. Today, these interfaces are generally physical but in some instances can include a market dimension as well. The physical interfaces include a DG unit's interaction with the fuel and electrical infrastructure. Some forms of DG will involve a communications interface with a central entity that controls and/or monitors the DG system. Physical interfaces are mainly concerned with issues such as safety, protocols, system impacts, reliability, standards, and metering. The market interface covers how the DG unit or its owner interacts or competes with other suppliers in the marketplace. The market interface includes concerns over dispatch, tariffs, pricing signals, response, and business and operational decisions. An overview of the DG interfaces is shown in Figure 2.

Figure 2: Distributed Generation Interfaces



While there are issues surrounding all of these interfaces (see Figure 3), the most important issues in the short term are on the electrical interface. The most contentious issues in the electrical interface are those involving DG interconnected to the grid and, consequently, are the focus of this white paper.

Figure 3: DG Interfaces

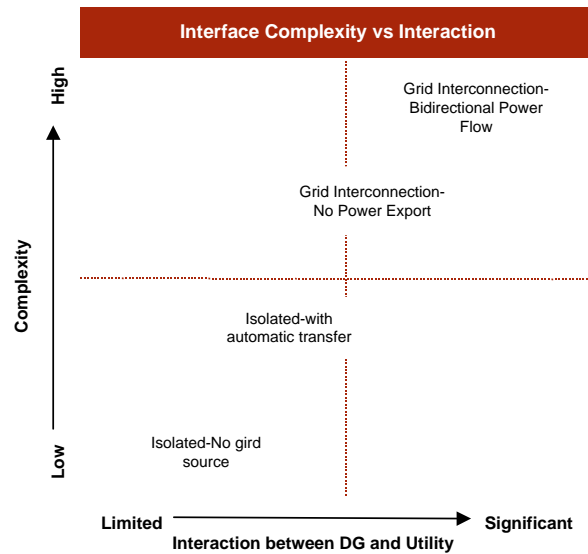


The complexity of the interface increases with the level of interaction required between the DG unit/owner and the electrical grid/distribution company.

Electrical Interface

The electric power system interface is the means by which the DG unit electrically connects to the power system outside the facility in which the unit is installed. Depending on the application and operation of the DG unit, the interface configuration can range from a complex parallel interconnection, to being non-existent if the DG unit is operated in isolation¹. The complexity of the interface increases with the level of interaction required between the DG unit/owner and the electrical grid/distribution company (see Figure 4).

Figure 4: Electrical Interface Complexity with Respect to Interface Configuration



Grid interconnection is the most complex electrical interface configuration and the source of many issues involving DG. As such, it will be explored in detail in this white paper. The term “interconnection” is often used synonymously with the terms “synchronized operation” or “parallel operation”. In this configuration, the DG unit is connected to the electric grid system while it generates electricity. Some states and utilities are already experienced in grid interconnection of small generators because of the small non-utility generators that were brought on-line under the Public Utility Regulatory Policy Act (PURPA) of 1978². However, these generators tend to be larger (>5 MW) than some of the emerging DG technologies. The typical cost of grid interconnection ranges from \$50/kW - \$200/kW depending on the size of the generator, application, and utility requirements. Higher costs are not uncommon for smaller units or where complex technical requirements are encountered.

1. See Appendix for more detailed explanation of the electrical interface configurations.
2. PURPA provides incentives for qualifying facilities. Qualifying facilities have to meet certain requirements in terms of operation, efficiency, fuel, size, and ownership. Utilities must pay a qualifying facility for purchased power based on the avoided cost - the incremental cost of power the utility would have had to pay if it generated the power itself or purchased it elsewhere.

Why is grid interconnection important?

Grid interconnection is important for three reasons:

1. The number of small generators seeking interconnection to the grid could increase in the future.
2. DG advocates contend that the current interconnection requirements and processes are effectively increasing costs unfairly and pricing DG out of the market.
3. Distribution companies are concerned that DG will negatively impact the safety and reliability of the grid and unfairly increase the distribution companies' cost (see Box on next page).

The diagram in Figure 5 shows DG applications and the range of interface configuration that could be used. Some of the DG units installed today for peaking and baseload applications are interconnected to the grid. As shown in Figure 1, these applications are growing at a fairly rapid pace. Power quality and combined heat and power applications are also sometimes interconnected to the grid. In addition, there are a number of promising emerging applications for DG that will also require grid interconnection³. For example, DG can be used to provide T&D support or ancillary services (see Box on next page).

The next section of this paper explores in more detail the issues and concerns for both the distributed generator and the distribution company. It will examine the issues arising from the current state of interconnection requirements and processes and then consider possible solutions.

Figure 5: DG Applications and the Electrical Interface

Application	Interface Configurations				Today	Emerging
	Isolated - No grid source	Isolated - with automatic transfer	Grid Interconnection - no power export	Grid Interconnection -bidirectional power flow		
Standby/Back-up		↔			✓	
Peak Shaving (Onsite loads)		↔	↔		✓	
Baseload (Onsite Loads)	←	↔	↔		✓	
Combined Heat and Power	←	↔	↔	↔	✓	
Power Quality	←	↔	↔	↔	✓	✓
Electricity Sales				↔		✓
Ancillary Services	←	↔	↔	↔		✓
T&D Support	←	↔	↔	↔		✓
Microgrids	←	↔	↔	↔		✓

3. While some of the benefits of these emerging applications can be realized without grid interconnection, grid interconnection will be required to maximize the overall penetration and benefit of these applications.

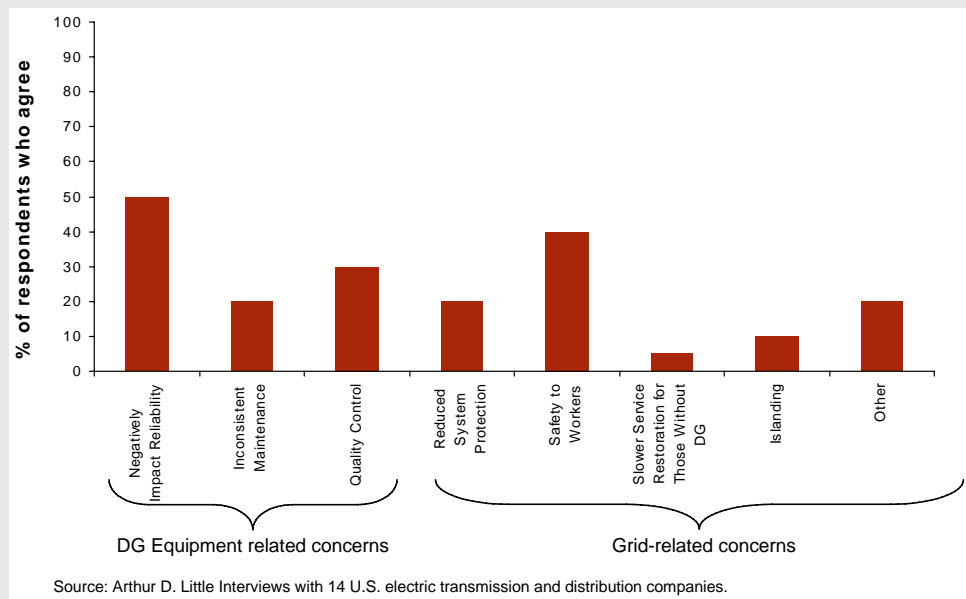
Utility View on Interconnection

Arthur D. Little conducted a series of interviews with electric distribution companies. These interviews revealed that distribution companies consider their primary goal to be the reliability of the electrical system and the safety of utility employees. Thus, any interconnection requirements or standards should minimize potential impacts that DG might have on the electric grid.

Interconnection requirements for large DG installations (~10 MW) are well understood because they are very similar to the interconnections required for central power stations. Interconnection requirements for smaller installations are more difficult because the utility must balance the desire for a safe interconnection with the desire to have a "quick and easy" interconnection design to get the DG up and running. Interconnection complexity generally increases with project size and is technology dependent. Several utilities have a policy of bypassing standard stages of their interconnection process, such as inspection of protection systems and witnessing of protection system testing, if it has worked with a given company before on a similar installation.

Many utilities contacted felt that any negative operational impacts of DG should be handled through properly designed interconnection requirements. If the interconnection is properly designed, DG should not have any negative operational impact on the grid. Indeed, several of those surveyed contend that more small generation capacity would probably provide better grid reliability.

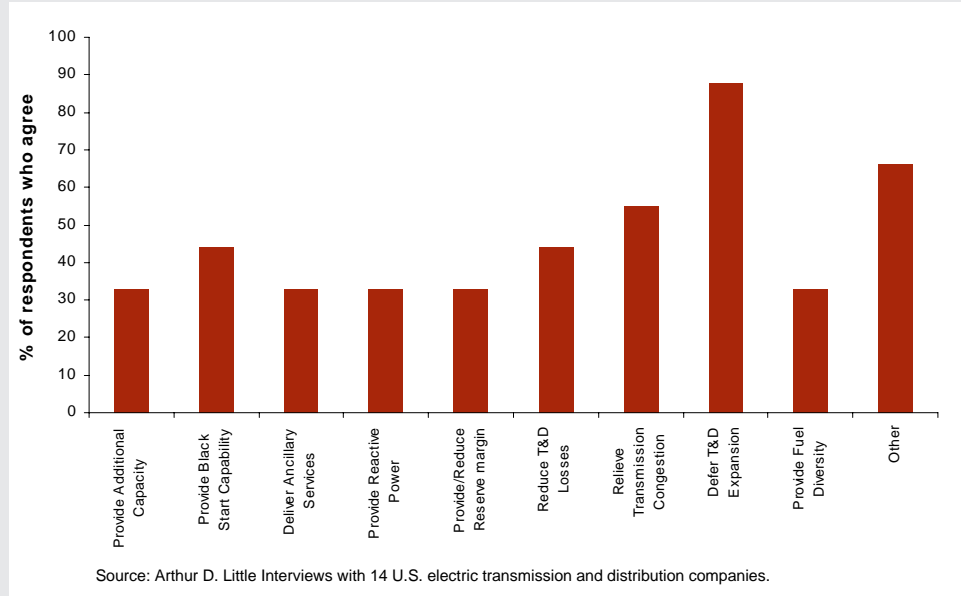
What are your concerns in regards to DG?



Utility View on Distributed Generation Benefits

Arthur D. Little's interviews with electric utilities staff revealed that many utilities feel that DG will have a positive impact on the grid and its performance. Utilities that are more dependent on a single fuel source, such as coal, view DG as beneficial for fuel diversity. Most utilities agreed that DG can be useful for T&D deferral in situations where natural gas (or some other fuel) is available in the congested area. However, utilities often view DG as a temporary answer to T&D problems rather than a permanent solution. For example, DG could be used to solve T&D problems caused by incorrect load forecasts or as a temporary remedy for load growth based system upgrades. However, most utilities indicated that if load growth is sustained, the utility would eventually elect to upgrade the system, if possible. Nonetheless, many utilities view DG as an excellent way to meet temporary or short term increases in electric demand. Realistically, however, although DG may lower peak demand, it would take a significant amount of DG to have a real impact. Similarly, many of the other potential benefits of DG will only come to fruition if a large amount of DG (on the order of 100's of MW) is installed. Thus, the number of units required makes DG impractical for some utilities. Several utilities felt that many DG technologies are simply too small to provide transmission support and are not really suitable for serving the transmission system as a whole. Utilities generally find it unrealistic to design line capacity based on customer sited peak shaving resources. However, if the utility could control the customer-sited DG or the DG were located on the utility side of the meter, this concern would be moot.

What are the benefits that DG can provide to the grid?

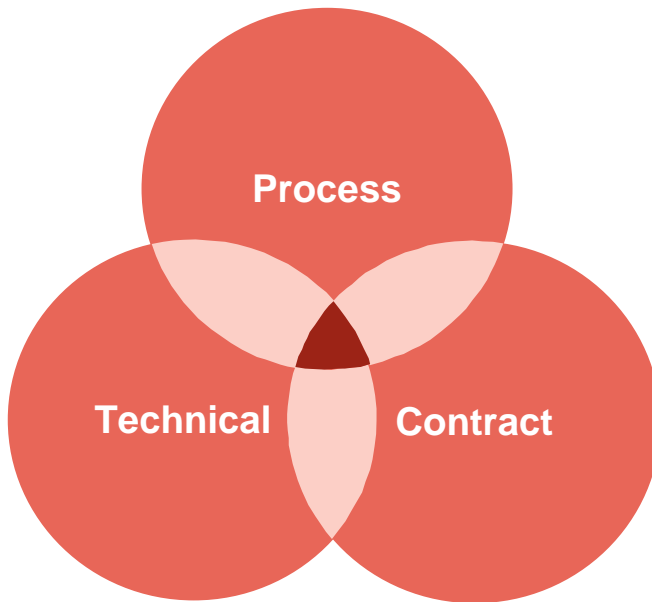


III. Interconnecting DG Today

Today's electrical power delivery systems are well suited to do what they were designed to do: deliver electricity from multiple large generators to serve multiple dispersed loads. The vast majority of existing generating facilities are central plants connected to networked transmission systems. Utilities have limited experience, however, interconnecting large amounts of small-scale generation to their distribution systems.

As shown in Figure 6 below, there are three overlapping elements of interconnection, that must be addressed in concert to ensure that all the issues are uncovered and dealt with in a systematic manner. Much of the discussion and debate surrounding DG interconnection has centered on technical issues. However, process and contractual issues merit equal consideration since they are key drivers in the cost, schedule, and quality control of the interconnection package.

Figure 6: The elements of interconnection



Technical

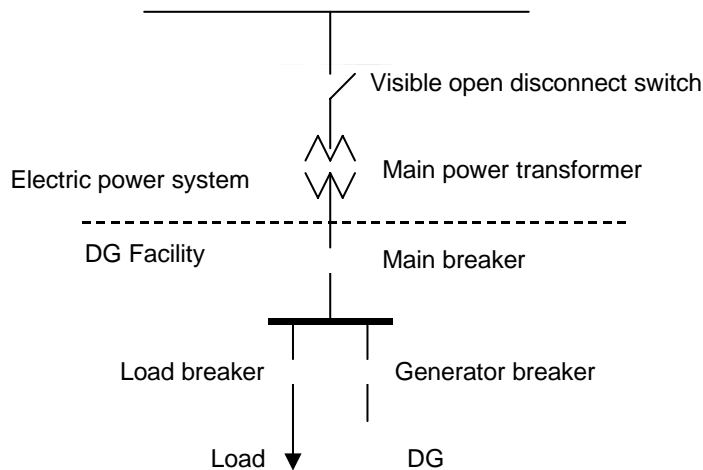
A typical interconnection system includes three kinds of equipment:

1. Control equipment for regulating the output of the DG
2. A switch and circuit breaker (including a "visible open") to isolate the DG unit
3. Protective relaying mechanisms to monitor system conditions.

Figure 7 shows a typical parallel interconnection configuration between DG, the loads it serves, and the electric power system.

Much of the discussion and debate surrounding DG interconnection has centered on technical issues. However, process and contractual issues merit equal consideration since they are key drivers in the cost, schedule, and quality control of the interconnection package.

Figure 7: One-line diagram of a typical parallel interconnection



The protective functions typically used for DG require measurement of voltage and current. Voltage measurement can be used for fault detection, and detection of abnormal system conditions such as a de-energized utility distribution line. Current measurement is used to detect overloads and fault conditions within the generator and within the utility system⁴.

Utilities develop interconnection technical requirements to maintain grid performance and minimize any negative operational impacts of DG. In addition, a properly designed interconnection is critical to ensuring safety to line workers. During maintenance or an outage, a proper interconnection solution will prevent a distributed generation unit from energizing a section of the distribution system where a lineman is working.

Interconnection requirements are not currently standardized as there are no nationally recognized standard for interconnection (see Box on next page). This is in part because of the difficulty in standardizing protective equipment since the type of equipment needed to ensure safe interconnection depends on many factors, including:

- *Generator type*
- *Size of generator*
- *System voltage*
- *Location in the distribution system*
- *Radial versus networked distribution system*⁵

Some DG developers consider existing technical requirements unreasonable and believe that they discourage customers from pursuing DG. The technical requirements for each interconnection vary from one utility to the next and also from one project to the next. Not all utilities have established well-defined technical requirements for interconnection.

4. In addition to over/undervoltage and overcurrent functions, voltage and current measurement is used for over/under frequency, synchronism, and voltage imbalance.

5. See appendix for more detailed discussion of DG in radial and networked distribution systems.

The central issue in the technical area is whether standards can be developed that will allow for a cost effective interconnection solution without jeopardizing the safety and reliability of the electric power system.

Institute of Electrical and Electronics Engineers (IEEE) Effort to Develop a Nationwide Technical Interconnection Standard

Interconnection requirements are established by utility distribution companies and vary from utility to utility. The Institute of Electrical and Electronics Engineers (IEEE) is now developing a universal set of interconnection requirements that is expected to provide highly credible, standardized technical guidance on this topic. The IEEE is well known as the largest professional society of its kind, with over 320,000 members worldwide. Volunteers from various professions develop its electrical standards on a consensus-basis, which are widely accepted. Developing a standard in this manner ensures quality and widespread acceptance, but is a time consuming process. IEEE's Working Group P1547 (Standard for Distributed Resources Interconnected with Electric Power Systems) began work in the spring of 1999. Volunteers from over 60 organizations including utilities, independent power producers, equipment manufacturers and consulting firms are working on this standard and meet quarterly in an open forum.

This process is on a fast track and is being supported through the U.S. Department of Energy. Despite this support, the standard is not expected to be approved until the year 2002. IEEE has also developed P929 (Recommended Practice for Utility Interface of Photovoltaic Systems) that should be available in the year 2000. Until these standards are released, state regulators may choose to develop their own interconnection standards, or they may be requested to rule on the adequacy and fairness of the technical requirements of individual utilities. Once the IEEE standard is available, it will have to be adopted by utilities.

Those that do have such requirements in place usually state the minimum requirements necessary which are subject to then change with each interconnection. Many of these technical requirements were developed to interconnect large (>50 MW) qualifying facilities. Few of these existing requirements were established to account for small generation technologies such as DG and the specific needs related to dispatch, metering, and power quality. Protection equipment is sometimes specified to prohibit relaying equipment from being contained within a single device. This reduces the probability of total system failure as a result of the failure of a single component. This redundancy is something that many DG owner/operators object to because it can increase project cost and design complexity.

As DG technologies have evolved, many suppliers have developed alternative solutions to traditional interconnection designs. Suppliers are moving toward integrating these solutions into their DG packages to lower the overall cost of the system. In order to ensure safety and reliability, utilities must test each alternative solution before it can be integrated with a utility distribution system. Consequently, some of the newer integrated solutions are not readily embraced by utilities.

The central issue in the technical area is whether standards can be developed that will allow for a cost effective interconnection solution without jeopardizing the safety and reliability of the electric power system. In addition, new technical requirements must be developed that address the emerging needs of DG for dispatch, metering, communication, and control standards.

Process

While many utilities have (or are developing) standard processes for design, approval, and inspection of the interconnection equipment, many more do not have a standard process or one that is transparent to the customer. Similar to the situation described regarding the technical requirements of DG interconnection, many of the processes that do exist today were developed for large qualifying facilities rather than DG. These processes have many requirements that may not be necessary for smaller facilities that are not going to export power.

Whether or not a process is in place, most utilities utilize a similar set of steps or milestones, each of which must be passed in order to interconnect the DG unit with the electric power system:

1. *Initial contact with the utility*
2. *Exchange of general project information between the customer and the utility*
3. *Engineering analysis by the utility*
4. *Customer acceptance of interconnection design*
5. *Engineering/project review meetings between the utility and the customer*
6. *Project engineering and construction*
7. *Final utility inspection of interconnection and protective equipment*

Figure 8 details the interconnection process that has been specified for a large investor-owned utility. There are generally no shortcuts—customers must follow these steps regardless of the size of their DG facility. The utility performs an engineering analysis to determine the impact that the installation will have on worker safety, system protection, and system operation. Some utilities charge interconnection applicants a fee for this analysis. The fee often varies according to the complexity of the interconnection. The utility may require prepayment and charges must typically be paid even if the applicant abandons the project. From the utility's perspective, the effort expended to analyze a design proposal is an expense that must be recovered regardless of project outcome. Utilities do not always grant customers and DG developers access to these studies. A typical timeline is shown in Figure 9. There are generally no time limits associated with specific stages or milestones.

In some cases it is necessary to change or upgrade the utility distribution system to support a new DG plant that is interconnected to the electrical grid. Alterations to the grid system may involve line extension and other modifications to facilitate power flow in the opposite direction of the normal power flow to ensure grid reliability. The DG developer must fund any modifications of this nature.

Obtaining interconnection approval is a dynamic process that depends on the details of a specific project and often requires numerous meetings with several different divisions within a utility company. A minor adjustment or change in the engineering plans may necessitate further analysis of the interconnection plan by the utility. Likewise, a utility may discover that additional equipment or a different configuration of system protection is required in order to guarantee safety and reliability after it has already approved a DG system design. In situations in which grid reliability is at stake, any necessary changes must be carried through.

Whether or not a process is in place, most utilities utilize a similar set of steps or milestones, each of which must be passed in order to interconnect the DG unit with the electric power system.

Figure 8: Interconnection Process of a Large Investor-Owned Utility

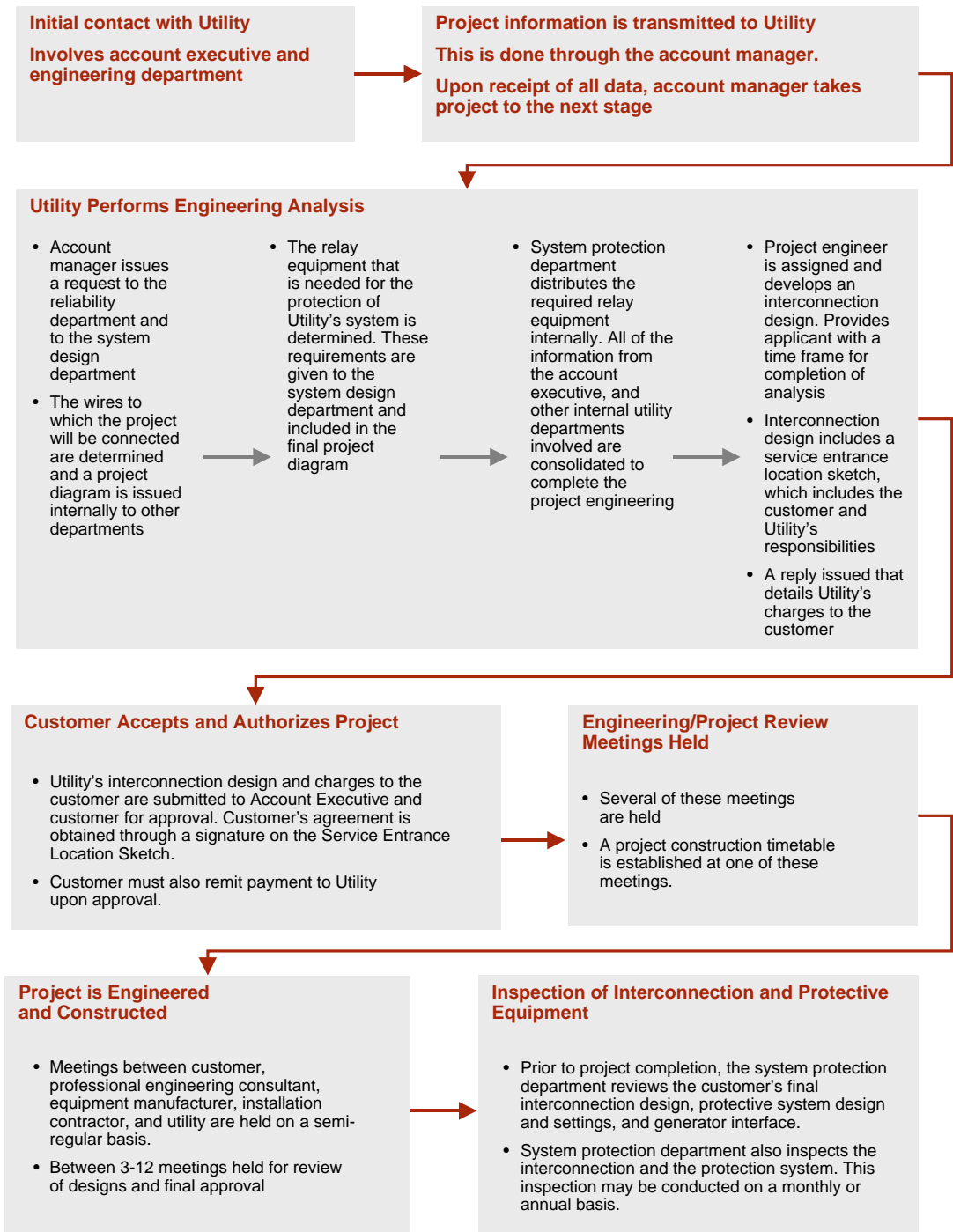
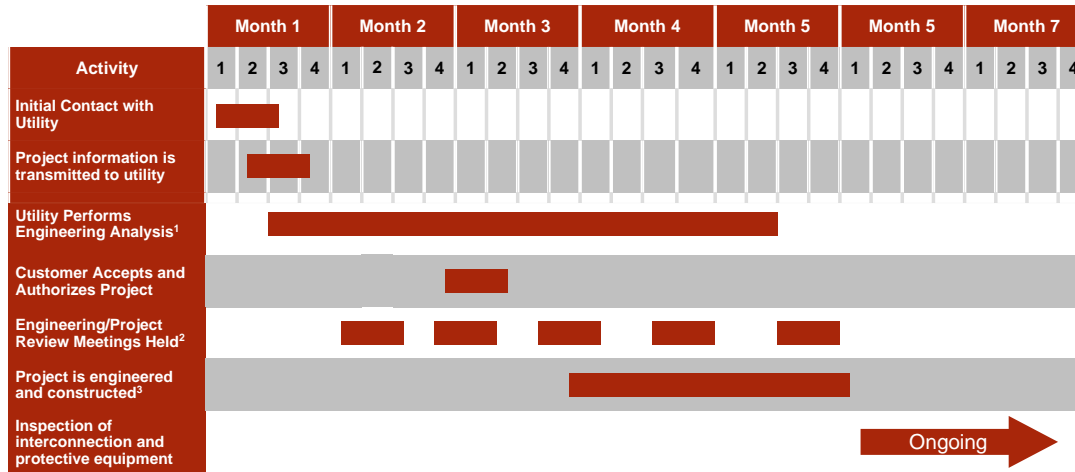


Figure 9: Typical Interconnection Schedule



Note: All times are approximate and can vary widely by size of project, location of project, configuration of project, and host utility.

1. Engineering analysis may take up to one year depending on DG technology, installation size, and installation location.
2. Meetings are held intermittently and depends on several factors.
3. Project engineering and inspection may take as little as three months or as long as one year.

Many prospective DG customers find this process to be onerous and time consuming. Without defined limits, (e.g., a utility must respond to application for interconnection within 10 working days), the schedule may be delayed thereby making it difficult for the applicant to plan other aspects of the project. If the applicant experiences lengthy delays moving through the process, there is generally no recourse. This is no small matter. Lengthy delays in gaining interconnection approvals can cause project costs to increase dramatically and may even render a project economically unfeasible. Furthermore, because interconnection equipment is often purchased prior to full knowledge of specific requirements, developers often find they must redesign portions of their system and purchase more equipment, both of which are costly and further delay the project. It can take anywhere from months to years in order to get permission to operate in parallel with an electric grid system. Long lead times can cause increased project costs and even render projects that are otherwise viable to be economically unfeasible.

If an applicant is dissatisfied with the utility's evaluation of the interconnection, there is no guarantee of recourse or simple process to settle disputes. A developer can either comply (if this is possible) or choose not to complete the project. Certain states/utilities that have adopted qualifying facility (QF) interconnection processes for DG stipulate that the applicant can turn to the state public utilities commission for mediation. However, the use of QF interconnection rules for DG interconnection is not necessarily adequate due to differences between DG and larger power producing installations. For a small DG facility, this particular recourse can be prohibitively costly and time-consuming.

A key interconnection issue is the development a process that is transparent to the customer and efficient without unduly burdening distributed generators or distribution companies.

Case Study: Interconnection Practices from a Customer Perspective

It is not uncommon for distributed generation projects to encounter expensive interconnection disputes that pit local utilities against their customers. In some cases, a cumbersome or ill-defined interconnection process could cause delays, confusion and mistrust on the part of the customer. Ultimately, the project developer may relent simply to avoid further delays and increased costs.

An urban district heating plant in the Northeast wanted to install a 500 kW cogeneration system to serve 90% of the plant's electrical load. In July 1996, the owner submitted an interconnection request that proposed to interconnect within the current, networked distribution system. The utility customer representative gave verbal approval for this interconnection, something that he was not technically qualified to do. The owner proceeded to complete the installation of the cogeneration plant in December 1996. One week prior to start-up, the utility's system protection group informed the owner that it was necessary to modify the plant's electrical service to accommodate a radial distribution interconnection. This led to an unfortunate stalemate between the utility and the owner that lasted for 2½ years.

One of the major roadblocks for this project was poor communications and a perception on the part of the customer that he did not receive adequate guidance from the utility. The facility manager reported that the utility did not respond in a timely, definitive manner to his initial interconnection proposal and subsequent proposed solutions. The owner was further frustrated by his inability to communicate directly with the utility's technical division to work out a mutually acceptable resolution.

Rather than proceed with a costly formal hearing before regulators, the owner chose to accept the utility's proposed solution and proceed with the project. This decision came at a cost: selection of the radial system design added approximately \$400,000 to the project, doubling the payback from two to four years. The project was scheduled to come on line in August 1999.

A key interconnection issue is the development a process that is transparent to the customer and efficient without unduly burdening distributed generators or distribution companies. The formidable task to creating efficiency will be to streamline existing processes - taking into consideration smaller size generators- while ensuring that safety or reliability is not compromised.

Contract (Interconnection Agreement)

An interconnection agreement is a contract between a DG owner and the utility within whose power delivery system the DG shall be interconnected. Terms of the interconnection agreement used for DG vary by utility and according to the characteristics of the DG installation. The typical interconnection agreement includes the responsibilities of both parties to ensure that the interconnection equipment is installed and properly maintained. The agreement typically grants the utility access to the customer's facility for routine inspections. The contract between the utility and the DG owner operator also specifies liability and the amount and coverage of insurance that must be carried.

An interconnection agreement can also specify the metering for the DG facility.

Typically, the metering configuration can involve two separate meters (power in, power out) or one net (bi-directional) meter. In states that require net metering, a single meter measures the difference between the electricity consumed by the customer and electricity exported to the grid. Hence, the meter will record the net energy received by the facility or, if the facility generated more than it consumed, the energy delivered to the grid. Depending on the state, the utility may be required to pay the customer the avoided cost or the retail price for the excess electricity delivered to the grid. Regardless of the metering configuration, the DG owner is responsible for providing approved metering equipment and for providing the utility access to meters at all times. Power sales and power purchases are addressed under two separate agreements.

The central issue on interconnection agreements is the complexity and the appropriateness of particular standard requirements to DG. A contract between a DG owner and a utility are similar to a contract between a central power facility and a utility in many respects. Many of these contracts are lengthy and complicated. While developers concede that such contracts are suitable for a 200 MW facility, there are many requirements included in the standard contracts that are not appropriate for a 200 kW facility. For a large central power plant, the liability and insurance on a per kW basis is typically fairly low. DG owners may need to carry the same amount of coverage, making its per kW cost significantly higher.

Figure 10: Interconnection Issues and Solutions

Issues	Possible Solutions
Technical	
<ul style="list-style-type: none"> • A properly designed interconnection is essential to minimizing any negative operational impacts of DG • Utility requirements that exist state the minimum requirements and are subject to change with each interconnection • Technical requirements vary by utility • Existing requirements do not account for emerging applications and needs for dispatch, metering and power quality • Existing requirements perceived by some as unreasonable 	<ul style="list-style-type: none"> • National or statewide technical standards or guidelines that include emerging applications developed by all stakeholders • Utility developed standards developed by all stakeholders and approved by a third party
<ul style="list-style-type: none"> • Alternative solutions and technologies (new and existing) particularly for integrated devices are not readily accepted by utilities • In order to ensure safety and reliability, utilities must test each alternative solution before it can be integrated with the distribution system 	<ul style="list-style-type: none"> • Third party verification of alternative solutions • Pre-certification process controlled by an independent third party
Process	
<ul style="list-style-type: none"> • Lack of defined process at some utilities or process and technical requirements limited to Qualifying Facilities • Perceived lengthy, onerous process at some utilities • Process controlled by a utility that views DG as competition 	<ul style="list-style-type: none"> • Streamlined process covering all DG applications developed by each utility with input from stakeholders and approval by a third party • A statewide or national streamlined process for interconnection developed by all stakeholders that covers all DG facilities with timelines
<ul style="list-style-type: none"> • Lack of timely and efficient settlement of disputes • Results of interconnection analysis not always made available to customers 	<ul style="list-style-type: none"> • Independent technical body to efficiently resolve interconnection disputes in a timely manner
<ul style="list-style-type: none"> • Interconnection studies are required in some states no matter the size of the facility • Customers must pay for studies the utility performs on interconnection based on fees set by the utility 	<ul style="list-style-type: none"> • Appropriate guidelines for interconnection studies included in statewide or national standard process outlining responsibility for cost, appropriate fees and scope of study • Third party interconnection studies
Contract (Interconnection Agreements)	
<ul style="list-style-type: none"> • Utilities generally do not have standardized contracts for interconnection. Those that do cover qualifying facilities and are more complicated than necessary for DG. • Contract length and complexity not in line with size of the DG facility • Universal indemnification required by some utilities • Interconnect agreements require customers to carry general liability insurance to cover utility's interests 	<ul style="list-style-type: none"> • National or statewide standard contracts whose complexity varies with size

Possible Solutions

While there may not be clear-cut solutions that would fully satisfy both utilities and DG owners, both parties have a common interest in resolving some of the issues surrounding DG interconnection. Figure 10 presents some possible solutions. This is not a comprehensive presentation but illustrates two important courses for resolution; standardization and third-party participation.

There is little question that a national (or even statewide) interconnection standard would be valuable in resolving some of these issues. However, a standard could be limited in that it cannot cover every possible case of interconnection. A national standard would have to be accepted by each state and utility and would be adapted to suit particular needs. Standardizing the process or interconnection agreements would be more difficult than technical requirements given existing state laws and overlapping jurisdictions. In addition, standard contracts may limit some needed flexibility for both customers and utilities. A first step might be the development of a boilerplate or guidance for states and utilities on recommended interconnection practices.

The involvement of all stakeholders is critical to resolving these issues in a manner that is acceptable to all. Third-party entities (separate from customers, developers and utilities) could play a role in both issue resolution and implementation. However, entities capable of taking on all the roles presented in Figure 10 may not exist or be capable of taking on this role. In addition, including an additional entity may actually increase costs and cause more confusion thereby further circumventing the interconnection process.

There are two important courses for resolution; standardization and third-party participation.

IV. The Future of Distributed Generation Interfaces

DG interfaces will likely change dramatically to facilitate the special characteristics and applications of DG.

In the future, DG will still need proper interfaces as it does today. However, the kinds of interfaces we can expect are impossible to predict beyond the certainty that they'll most likely change dramatically to facilitate the special characteristics and applications of DG. Figure 11 illustrates some possible future scenarios for how these interfaces could change.

Figure 11: Interfaces in the Future

Interfaces	Today	Possible Future (2005)
Electrical	<ul style="list-style-type: none"> • Customized interconnection solutions • Technical requirements vary by utility • Varying levels of complexity in the process and contracts • Process controlled by utilities 	<ul style="list-style-type: none"> • Plug and play interconnect solutions <ul style="list-style-type: none"> – integrated with the DG product – satisfying all technical standards – verified and certified by third party • National or statewide standards • Standardized process and contracts that streamlines interconnection making it doable for all customer classes
Fuel	<ul style="list-style-type: none"> • Larger DG units (>1MW) installed upstream in the natural gas distribution system 	<ul style="list-style-type: none"> • Smaller DG units - perhaps to the small commercial or residential level - will be installed further down the natural gas distribution system • Increased throughput and expanded distribution system • Other fuel infrastructures, in addition to natural gas, may be developing
Communications	<ul style="list-style-type: none"> • Remote monitoring for O&M purposes 	<ul style="list-style-type: none"> • Development of systems, standards and protocols for communications systems for: <ul style="list-style-type: none"> – Dispatch – Control • DG ISO to control and dispatch units
Market	<ul style="list-style-type: none"> • Access through limited tariffs only 	<ul style="list-style-type: none"> • Expansion and modification of available tariffs to include: <ul style="list-style-type: none"> – sales to grid – ancillary services – choice of back-up service • Access to markets <ul style="list-style-type: none"> – real time pricing signals – distribution only tariffs

Many of the changes we will see regarding the electrical interface are well underway already. DG equipment manufacturers and suppliers are beginning to refine and improve their products to facilitate standardization and interconnection solutions, and possibly integrate the interconnection solution within the DG package. While some of this will happen on its own, standards will still be required to allow manufacturers to offer plug-and-play products based on standard technical requirements that would be acceptable to all utilities. IEEE is already attempting to complete the first edition of its standards on interconnection of distribution generation. These standards are expected to consider, in one way or another, every possible impact that DG could have on an interconnected power system. As DG manufacturers, project developers, owners, and utilities adopt

these standards and guidelines, they will undergo that iterative process of refinement until they are widely considered acceptable for safe and reliable interconnection. These products may be tested by an independent third party and certified as meeting all requirements for interconnection. It may become clear that regulatory intervention is called for to streamline contracting and the overall process to make interconnection readily accessible to all customers.

It may ultimately be the communications interface that undergoes the greatest change over the next several years.

FERC issued an Order in 1996 that required utilities owning transmission assets to provide open access to the system to outside parties who would then pay for such use. This Order included a pro forma tariff after which transmission owners were to model their tariffs. Within this tariff was the recognition that some transmission customers would make requests for service that required the modification or upgrade of the transmission system (or other parts of the power delivery system). The tariff outlined the general processes for requests for transmission service: "System Impact Studies" and "Facilities Studies".

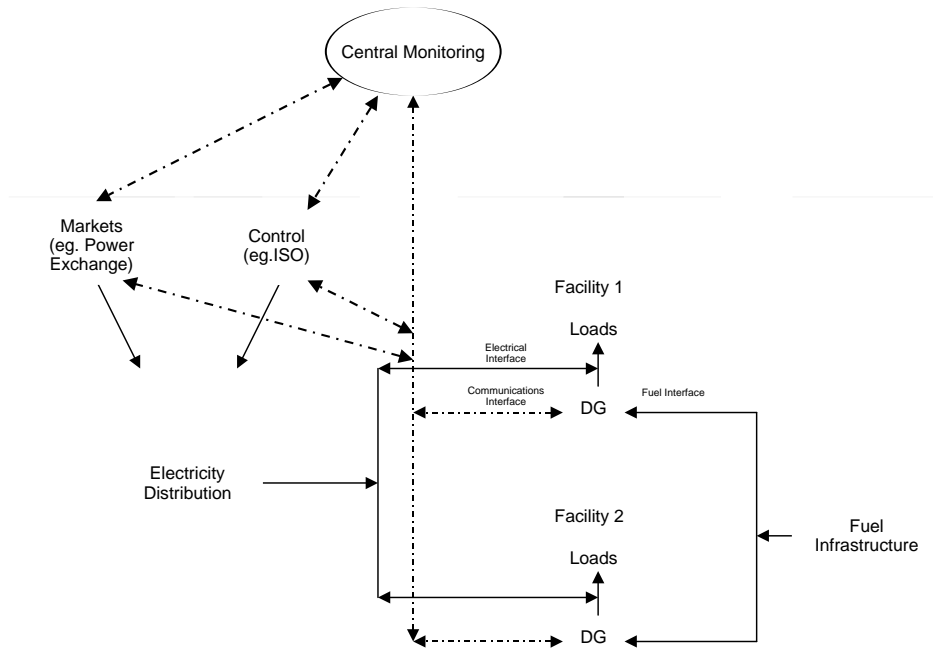
These studies parallel the interconnection processes described in this white paper. Perhaps a similar Rule Making at the Federal or state level regarding access to the distribution system would introduce some urgency to the issue of standardization of interconnection procedures. A key difference here, however, is that distribution systems fall under the jurisdiction of the states and their public utilities commissions. These are the same institutions that also have responsibility for implementing retail access policies. Conceivably, policies for interconnection of DG could emerge as a byproduct of retail competition.

The fuel infrastructure interface is not likely to see much change. The emergence of smaller DG technologies—microturbines and fuel cells—would cause DG to be installed further down into the natural gas distribution system at the small commercial and even residential customer level. It is conceivable that adoption of DG could cause a reexamination of the available capacity and pressure of natural gas distribution systems. We may also see the emergence of alternative fuel infrastructures—hydrogen or methanol—to accommodate fuel cell technology. However, this is not likely to happen before the year 2005.

It may ultimately be the communications interface that undergoes the greatest change over the next several years. Figure 12 shows how the communications interface may be expanded to allow DG to be controlled and dispatched, responding to market signals. Before such a system could be built, DG would need access to these markets. An interface of this type would necessitate the development of standards and protocols. It may also require the development of an ISO to serve DG needs, an organization that might have similar functions to ISOs we see today.

Realization of the full potential of DG in the future depends on expansion of market interfaces through innovative tariffs, broadened access to markets or the creation of distribution level power markets.

Figure 12: Expanded Communications Interface



Realization of the full potential and maximization of the benefits of DG in the future depends on expansion of market interfaces through innovative tariffs, broadened access to markets, or the creation of distribution level power markets. This could include the expansion of tariffs that would allow distributed generators to be compensated for excess electricity they export and for the benefits they can provide to the grid. Back-up tariffs are likely to be modified and may offer customers different "flavors" of back-up protection. Real-time pricing would allow DG to compete more directly with central power plants. To further expand DG's access to the market and to allow DG to compete with other sources of power, a DG Power Exchange (PX) may be created. Distribution only tariffs would allow the DG owner to enter into bilateral contracts with other facilities and use the distribution system for transport. In the future, an owner of many distributed generators could network his assets to bid into larger power exchanges or to allow the units to back one another up.

V. Conclusion

While there is a significant amount of DG installed today, little of it interfaces extensively with the energy infrastructure. In the future, this is likely to change as more DG is installed and some of the promising applications for DG emerge. The most important interfaces in the near-term for DG is the electrical interface and, more specifically, grid interconnection.

The issues concerning grid interconnection go beyond the technical aspects of interconnection and include process and contract issues. The challenge will be to modify the existing requirements to make them more efficient, transparent, and standardized while maintaining the grid's high level of reliability and safety. Meeting this challenge in a manner that is fair for all parties will be difficult due, in part, to the complexity of the financial and technical issues involved.

There are two important courses for resolution of these issues: standardization and third-party participation. To a certain degree, some of these issues will be resolved on a volunteer basis or by individual companies. Some of the possible solutions, however, would require regulatory or legislative intervention with the involvement of all stakeholders.

In the future, the communications and market interfaces will undergo the most change. The communications interface may require the development of systems and appropriate standards and protocols to allow DG to be controlled, dispatched, respond to more complex price signals, and/or otherwise participate in power markets. To realize the full potential and maximize the benefits of DG, the market interfaces will need to be modified as well through such things as expanded tariffs, expanded access to markets, or the creation of distribution level power markets.

DG promises to significantly alter the design and operation of the interconnected power delivery system and the nature of the electric utility industry. However, before this can happen, several things must occur with respect to providing the reliable and cost effective interconnection of DG. If these issues are not resolved, DG may just become another interesting, but impractical technology. If the industry solves the challenges and issues outlined in this white paper, DG may become a key part of the restructuring of the electric utility industry.

If the industry solves the challenges and issues outlined in this white paper, DG may become a key part of the restructuring of the electric utility industry.

Appendix

Electrical Interconnection Configurations

Configuration	Type	Complexity
<p>1</p>	<p>Isolated - No Grid Source</p> <ul style="list-style-type: none"> • DG provides power for all loads completely isolated from grid • Utility provides no back-up or supplemental power 	
<p>2</p>	<p>Isolated with Automatic Transfer</p> <ul style="list-style-type: none"> • DG provides power to Load 2 for peaking, baseload or back-up power • Utility provides power to Load 1 and occasionally to Load 2 • DG does not operate in parallel for more than 0.1 to 0.15 seconds 	
<p>3</p>	<p>Grid Interconnected with No Power Export</p> <ul style="list-style-type: none"> • DG parallel with grid • DG provides peaking or baseload power to all or some loads • DG does not export power to the grid • Utility provides any supplemental or back-up power 	
<p>4</p>	<p>Grid Interconnected with Power Export - Customer Side</p> <ul style="list-style-type: none"> • DG operates in parallel with grid • DG provides peaking or baseload power to load and exports power to grid • Utility may provide supplemental and back-up power 	
<p>5</p>	<p>Grid Interconnected with Power Export - Utility Side</p> <ul style="list-style-type: none"> • DG provides peaking, baseload or back-up power for utility to provide to customer • DG operates in parallel with grid 	

Breaker Open
 Breaker Closed
 Normal Power Flow
 Alternative Power Flow



Radial versus Networked Distribution Systems

A general understanding of the general configuration of electrical distribution system will assist the reader in appreciating the technical challenges that DG will present as it is installed and operated. Power system design recognizes certain tradeoffs between complexity and cost in order to maximize economy and reliability. As a result, the general structure of the networked power delivery system differs from that of the radial power delivery system. The following is a description of each system. As we shall see, each structure offers its own benefits in terms of cost and reliability; system protection differs as well.

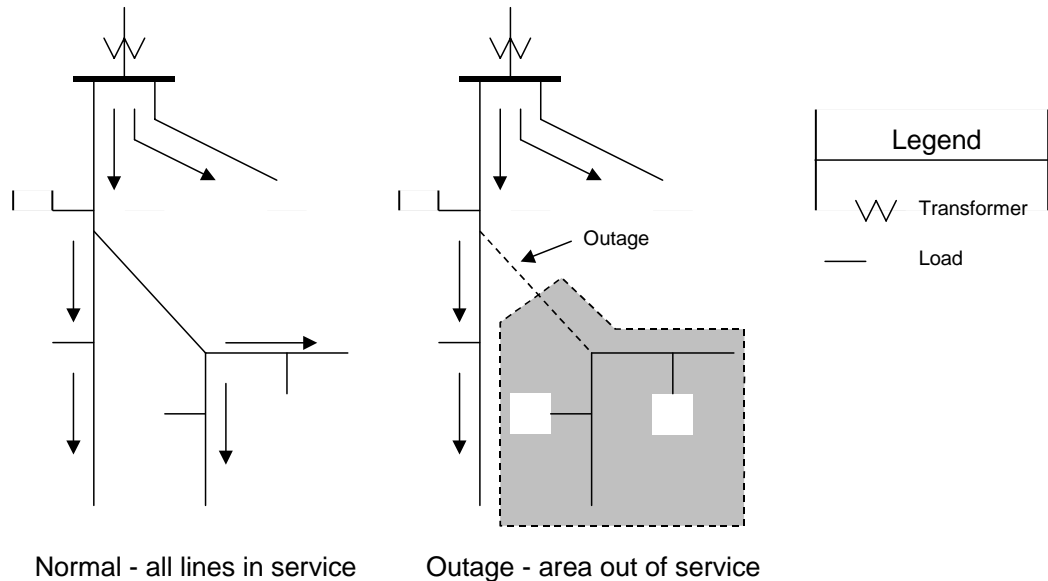
Radial distribution system

The existing distribution system is specifically designed to deliver electrical energy from substation transformers to end-use customers. Radial systems are designed with a substation transformer at the center and distribution lines radiating out toward the loads. While there can be many radial distribution lines emanating from a substation, each load is typically served by only one line. Moreover, the system is designed so that power always flows in one direction: from the substation to the load.⁷ A radial system generally offers a less reliable power source than a networked system because it lacks redundancy. However, the radial system and its protection equipment are less complex and less expensive than the networked system.

Figure A1 illustrates a radial distribution system. Under normal conditions, power flows from the substation transformer to customer loads over a series of distribution lines. The capacity of these lines is typically higher at the head of the circuit, and decreases closer to the load. Likewise, the protective equipment is designed to operate at lower current levels closer to loads. This enables the protection to be coordinated so those short circuits within the distribution system can be isolated so that they affect fewer customers. The introduction of an energy source such as DG within the radial distribution system poses a challenge to the engineers that design the protection system. This is because the source affects the load distribution in the system, and may even cause reverse power flow if it is large relative to the load. Introduction of a sufficiently large power source within the radial distribution would likely require some modification to the protection system.

7. In some cases small generators are present in a distribution system.

Figure A1: Radial distribution system

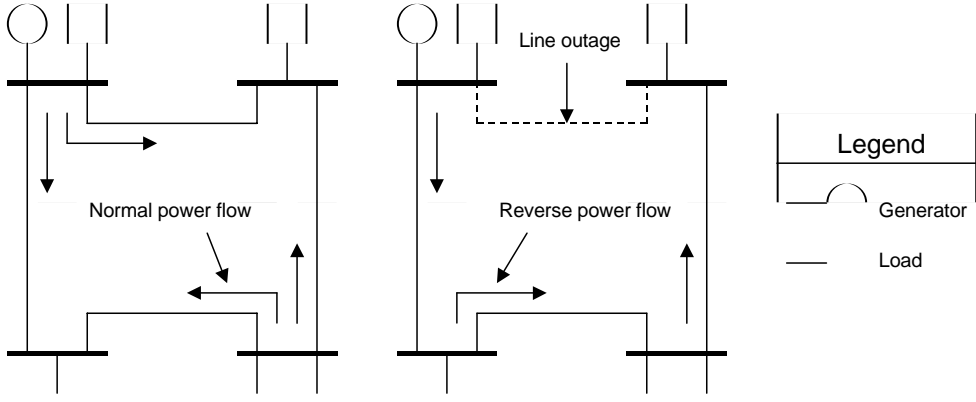


Networked distribution system

The networked distribution system is designed to provide highly reliable service to end-use customers. Often, these systems are employed in metropolitan areas using underground cables. The networked system offers reliability advantages over the radial system because it provides multiple power sources for loads. This multi-path design is sometimes referred to as a "looped" system.

System protection in a networked distribution system is more complex and expensive than in the radial distribution system. This is due to the extra intelligence needed for reliable, effective protection. In a networked system, it is possible for current to flow in both directions through a given system element (see Figure A2). Therefore, protective equipment often must be capable of determining current direction, as well as magnitude, and acting in different ways based on this information. Since the networked system is specifically designed to deliver energy from multiple transformers to loads, it is capable of dealing with reverse power flow. However, locating DG within the distribution system, particularly within the secondary network, could require modification of existing protection and switching systems. The extent to which modifications are required will depend on the design and condition of the electric power system into which the DG is connecting.

Figure A2: Networked distribution system



Normal - all lines in service

Outage - one line out of service

Sponsoring Organizations

AlliedSignal Power Systems, Inc.

Automatic Switch Co.

Caterpillar Inc.

Elliott Energy Systems, Inc.

Encorp, Inc.

Enercon Engineering

Fairbanks Morse Engines

Kohler Power Systems

Rolls-Royce Energy Systems

Solar Turbines Inc.

Siemens Westinghouse Power Corp.

Teledyne Continental Motors

U.S. Department of Energy

Zenith Controls, Inc.

For additional information contact:

Arthur D. Little, Inc.
Acorn Park
Cambridge, MA 02140
617-498-5000
www.arthurdlittle.com

David Klienschmidt
Vice President

Stan Blazewicz
Senior Manager

Arthur D Little