Distributed Generation for Power Quality and Reliability

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Abstract: Utility restructuring, technology evolution, public environmental policy, and an expanding electricity market are providing the impetus for Distributed Generation to become an important energy option today. While central power systems remain critical to the Nation's energy supply, their flexibility to adjust to changing energy needs is limited due to large, capital-intensive plants and T&D grid. Need for high investments and transmission losses have led to power shortages, unreliable and costly power being the 'rule' rather than exception. Interconnected Distributed Energy Resources can provide many beneficial services. At the most basic level, they can provide on-site electricity in the event of an outage on the electric power system. In more complex scenarios, appropriate interconnection technologies and policies can allow small energy producers to sell excess energy back to utilities. When effectively integrated into an electric power system, distributed power systems can be used to provide high-value energy, capacity, and ancillary services such as voltage regulation, power quality improvement, and emergency power. This paper reviews the potentials of Distributed Energy Resources for providing reliable and quality power in today's increasingly volatile market. The paper also throws light on the significant challenges that we face in making Distributed Generation an option.

Index terms: Distributed Generation (DG), Distributed Energy Resources (DERs), Power Quality, Reliability

I. Introduction

In certain commercial and industrial electrical applications, it is critical that "high quality" and "reliable" uninterrupted power be supplied; in order to prevent significant economic losses that can be incurred due to power cuts. In general, loss of productivity resulting from computer equipment failure, miscalculations and downtime has more impact than the physical effect on the equipment. Current worst-case estimates of economic losses directly attributable to power quality problems are in the range of $15 billion to $30 billion per year, which represent only 0.002% to 0.004% of annual U.S. output. Thus power quality may seem a "minor" issue, but it is not to those firms operating particularly susceptible product lines. Without good power quality, commercial buildings and industrial facilities can suffer from repeated equipment failures, safety hazards, process interruptions and shutdowns.

II. Background

The traditional model of electric power generation and delivery is based on the construction of large, centrally located power plants. Regardless of where power plants are located, their power must be brought from the plant to the users, and that's the purpose of the electricity grid. The grid consists of high-voltage transmission systems — carrying electricity from the power plants and transmitting it, if needed, hundreds of miles away — and the lower-voltage distribution systems, which run electricity from the transmission lines and distribute it to individual customers. The interface between the two systems is the electrical substation, which features "step down" transformers, circuit breakers and protection systems. Transformers located along the distribution lines further step down the voltage to 120 V or 240 V for household use.

Around 1985, electric utilities began to anticipate the likelihood of increased competition. Large power plants were viewed as a risky move and programs to encourage energy efficiency and load reduction (Demand-side management) became popular as one alternative to power plant construction. By the time wholesale electricity competition began in the United States, in 1996, utility investment in power plants had slowed considerably. Wholesale competition changed the way utilities operate and created the possibility of a complete restructuring of the electric power industry, with competition replacing regulation. Electric restructuring came quickly to California, and several other states followed suit. However, the overall process was slow. There was no incentive to build new power plants. The resulting lack of generation growth has led to tight electricity supplies in much of the United States, particularly in California, which experienced an electricity crisis in the summer of 2000.

III. Distributed Generation

Distributed energy resources (DER) refers to a variety of small, modular power-generating technologies that can be combined with energy management and storage systems and used to improve the operation of the electricity delivery system, whether or not those technologies are connected to an electricity grid. They are parallel and stand-alone electric generation units located within the electric distribution system at or near the end user. DER can be beneficial to both electricity consumers and if the integration is properly engineered, the energy utility. Their generating capacity is typically in the range of 3 to 50 MW.

Implementing Distributed generation can be as simple as installing a small generator to provide backup power or it can be a complex system, highly integrated with the electricity grid and consisting of electricity generation, energy storage, and power management systems.

Distributed generation can support and strengthen the central-station model of electricity generation, transmission, and distribution. While the central generating plant continues to provide most of the power to the grid, the distributed resources can meet the peak demands of local distribution feeder lines or major customers. Computerized control systems, typically operating over telephone lines, make it possible to operate the distributed generators as dispatchable resources, generating electricity as needed. In grid-connected applications, it involves using small electricity generators throughout the distribution grid to supplement the electricity supplied by a large, central-station power plant.

Drivers for DER: Utility Deregulation and the growing challenge of system reliability are the primary reason for the high level of interest in distributed energy resources.

Other drivers for DER include:

- Desire for alternative renewable resources such as solar and wind.
- Need for higher power quality in some commercial and industrial facilities as a result of increased use of microelectronic devices.
- Remote power applications and to reduce the high expenses incurred in transmission of power.
- Meets requirements for reduced emissions.

IV. Reliability Challenges

The U.S. electric system is in the midst of a huge transformation. The reliability of electric supply, long taken for granted by most citizens and governmental officials, is now a matter of primary concern. Rolling blackouts, electric price spikes, and power quality issues have become topics of daily news coverage and public debate. Issues such as Transmission overload (West-wide), Generation adequacy (New England, New Orleans, Midwest, CA 2000-01), Load pocket peaks (SF 2000) and Distribution overloads (Chicago, NY 1999 and 2000) challenge the reliability of the U.S. electric system. The California power crisis of 2000-2001and the major losses of electric load in the northeastern U.S. and Canada Eastern Interconnection on August 14, 2003 command national attention, but reliability problems in various forms are on the rise. *Can the traditional Central Stations handle this?*

Also there is an increasing need for *"high 9's"* power quality. As mentioned before, there is a growing need for extreme system reliability and quality power. Many industries are not satisfied with even 99% system reliability. 99% reliability indicates a power outage possibility for more than 3.5 days and the losses due to non-production and outage are very appreciable. The demand for more number of 9's, six or even higher is increasing. Figure 1 shows a tabular comparison of reliability and hours of outage.

# 9's	% Reliability	Outage
0	99%	87.60 hrs
1	99.9%	8.76 hrs
2	99.99%	52.56 min
3	99.999%	5.26 min
4	99.9999%	31.50 sec
5	99.99999%	3.150 sec

Figure 1: % reliability & Outage duration.

It is important to realize here that "reliability problem" is not a single problem, but a cumulative effect of many critical situations existing in the power system. Some of them are as described below:

• **Power Quality Demands**: There is a growing awareness that continuous power supply and improved power quality are critical to the high tech, digital economy. Our economy is increasingly based upon the continuous real-time flow of information, and increasingly dependent on machines controlled by computer chips. Even one cycle of outage or two cycles of a 25% voltage dip can cause unprotected microprocessors to malfunction. At an individual firm level, for example, the costs of shutting down a silicon crystal-growing process can threaten the financial health of a semiconductor manufacturer. Electronic controllers on variable-speed motors are even more vulnerable to voltage sags than are computers. Surges, spikes, transients, blackouts, noise and sags are all common names given to power quality problems.

In a recent study, DOE reported that the U.S. electric industry produces over 3.3 trillion kilowatt-hours (kWh) of electricity each year. At an average cost of $0.069 per kWh, that translates into a $229 billion industry. It is estimated that line losses, poor power factors and general inefficiencies waste 10% to 15% of the electricity generated, representing a potential loss of up to $33 billion worth of electricity annually. Part of this loss could very likely be recovered by implementation of power quality measures; for example, harmonic corrections which would tend to reduce line losses and premature equipment failure.

• **Load Growth:** Load growth in the United States, and particularly peak load growth, have been proceeding at a pace that has put great strains on our power system infrastructure. Between 1999 and 2000, non-coincident summer peak load in the US rose from approximately 1,271,011 MW to

1,790,181 MW — an change of *40.8%* in just one year [19]. According to many estimates, shortages are likely to develop in almost every one of the nation's 10 regional reliability councils in the next 5 to 7 years. The North American Electric Reliability Council (NERC) estimates the average peak demand growth over the next ten years to be over 2% per year. Figures 2 and 3 show the Peak demand and Net Energy for load projection by NERC for the next ten years [20].

• **Utility Deregulation:** Changes in the Power Quality demands and continued widespread load growth are accompanied by another very significant change in the electric industry: the deregulation of industry and consequently regulation replaced by competition. Though this change brought many benefits it also led to some critical reliability consequences:

A. The concept of integrated resource planning and integrated transactions (now occurring in the wholesale markets) no longer existed. This resulted in placing larger demands on transmission grids, and greater pressures on the entire electric infrastructure, less-controlled peak load growth, and thus, increased market power of generators, thin reserve margins and higher power costs generally.

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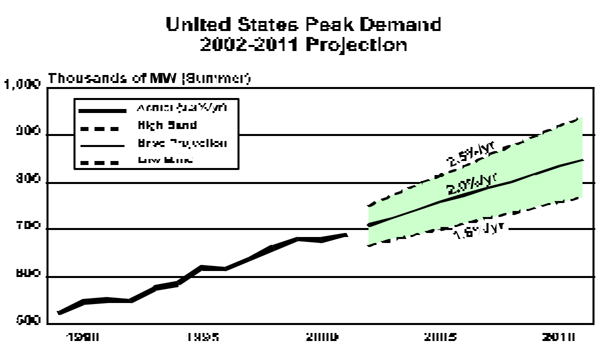

Figure 2: United States Peak demand projection for 2002-2011

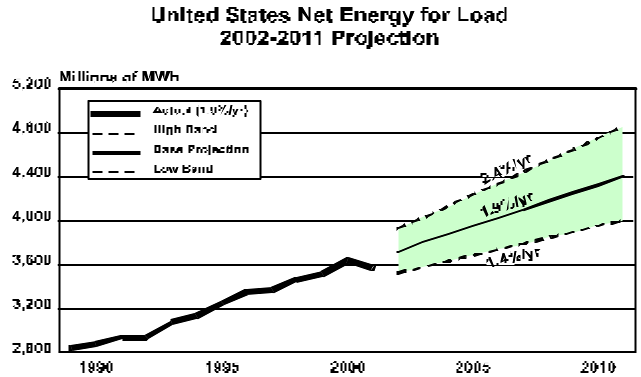

Figure 3: United States Net Energy projection for 2002-2011

C. Throughout the summers of 1998 to 2000, and into the winter of 2000-2001, major reliability problems in many regions of the nation have occurred that need no mention. In August of 1999, Secretary of Energy Bill Richardson formed DOE's Power Outage Study Team. The Team's purpose was to study significant electric power outages and other disturbances that occurred across the Nation during the summer of 1999 and to recommend appropriate Federal actions to avoid electric power disturbances in the future [21]. Eight of the most significant events from the were examined which concluded that the transition to more competitive wholesale markets and retail competition in many states had undermined the industry's traditional reliability mechanisms [22].

V. DG for Power Quality and Reliability

The potential contribution of Distributed Resources in view of the reliability and power quality issues mentioned above, bring in new opportunities for non-traditional electric resources to meet the needs of customers, electric systems, and the broader economy. In particular, distributed electric resources can address the needs of customers, meet load growth, and help to fill the reliability gaps. DER includes both demand-side and supply-side resources. Distributed resources include smaller-scale generation, energy storage, load management, and energy efficiency, as well as wires solutions. DER can provide reliability benefits such as end-use efficiency and demand management, customer-owned generation, customer supplied ancillary services, and customer responses to improved pricing signals in the power market.

Distributed generation technologies can be used to meet base load power, peaking power, backup power, remote power, power quality, as well as cooling and heating needs. Here we list some specific benefits related to Power Quality and Reliability.

- **Grid Support:** The power grid is an integrated network of generation, high voltage transmission, substations, and local distribution. Strategic placement of distributed generation can provide system benefits and preclude the need for expensive upgrades. DER has the potential to produce benefits on both sides of the electric meter.
- **Standby/Emergency Power:** Distributed resources can be used to provide on-site standby power for customers that require uninterrupted electric service 24 hours a day, 7 days a week. Customers that maintain distributed power systems for backup power may also be able to lower the cost of their power purchases by participating in peak load reduction programs offered by utilities.
- **Premium Power:** Distributed resources can be used for onsite generation can improve both power quality and power reliability, especially when backed up with grid-based power. Continuous customer generation applications produce power on a nearly continuous basis, running at least 6,000 hours per year.
- **Remote Power:** Residences and small commercial establishments (such as ranches, dairy farms and flower growers) that are located well away from the T&D system may opt to generate their power onsite. Thus they eliminate both the cost of connecting to the grid and any problems associated with their position at the end of a long T&D line. The elimination of problems, which include power outages and lower quality power, can produce the gripping economics necessary to further the use of DG in a remote power capacity.

The chart (Courtesy: www.eere.energy.gov) as shown in Figure 4[2], clearly shows a study of 275 DER installations found that issues with electricity supply is the main reason for using DER, where as reliability and PQ together is the 3rd most important reason.

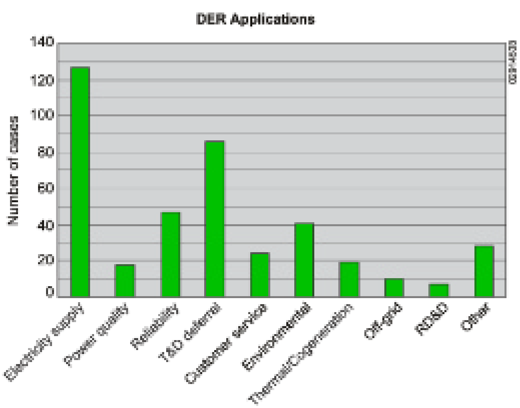

Figure 4: Survey Chart showing reasons for DER installations

VI. Market Dynamics

How will Distributed Generation help improve power reliability and financial stability in today's deregulated and competitive market? One of the salient features of restructuring is the introduction of competitive forces – making electricity like any other physical commodity. These competitive forces will increase the volatility of electricity prices. The result would be price spikes, which would depend on various factors. For instance, some price spikes will be localized based on transmission and distribution constraints. Other price spikes will be global, affecting an entire network. The following factors also deserve mentioning and need to be considered along with the price volatility issue mentioned above:

- The current power infrastructure faces an appreciable power crunch and is not able to meet the demand for high-quality, reliable power.
- Reduction in investments in generation owing to regulatory and political obstacles. Also, the restructuring of the power industry has resulted in reduced incentives for utilities to invest in new generating facilities.

Distributed Generation will not only provide small-scale power generating equipment with greater efficiencies, environmental advantages, and lower costs but also allow consumers to protect themselves from these often unpredictable 'shoot up' of prices caused by competition. This might be less expensive to the consumer than paying the high competitive price of electricity. Thus, distributed energy resources can be considered very promising in *providing a financial hedge and stability* in today's the increasingly volatile electricity market.

Thus the market for Distributed energy resources (DER) may be viewed broadly in two categories –

- *Energy Users' Market* – DER applications can offer energy users lower energy costs, increased reliability, and power quality and better management of demands.
- *Utility Market* – On a short-term basis, distributed power can reduce problems created by incorrect load forecasts or transmission and distribution shortfalls. The national average cost for adding transmission and distribution infrastructure is about $1,260/kW, so the savings are very significant (Source: "Distributing the Power", by Bhavesh S. Patel, Energy Markets, September 2001). Also, *strategic planning and positioning* of distributed power allows utilities to provide solutions to customer problems while maintaining market share and control.

A number of large industrial customers have accepted DG in providing back-up power and a potential market lies ahead from medium and small industrial customers. Distributed power in the form of IC engines, gas turbines and Micro turbines are being widely used currently in the U.S. Advances in new generating technologies have been moving toward small equipment with increased output, making on-site generation now feasible for commercial establishments and even residential energy users as well.

A large U.S. market exists for internal combustion (IC) engine-based combined heat and power (CHP) applications. The table in figure 5[3] below shows the use of the CHP technology and the increasing market for DG in general.

State	Number of Sites	% of U.S. Market
California	493	42.0
New York	136	11.6
New Jersey	117	10.0
Others	426	36.4

Figure 5: Table showing the use of CHP technology in various states in the U.S.

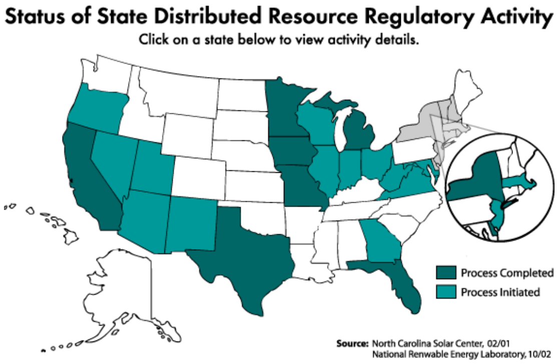

Figure 6: Status of Distributed resource activity

VII. Potential Challenges

Currently, DG installations must either comply with regulations applicable to large central power generating units or meet with regulations designed to facilitate energy conservation through renewable power or cogeneration. Although the Public Utilities Regulatory Policy Act of 1978 (PURPA) addressed many market barriers to CHP, new hurdles have emerged with the move to a competitive utility marketplace. There are a number of significant technical, economic and institutional barriers that hinder the deployment of distributed power technologies. Importantly, these barriers influence investments in capital equipment, and tend to "lock-in" continued use of polluting and less-efficient electricity generation equipment. The issues may be categorized as:

- **System Impacts of Distributed Generation:** Interconnection of a large number of distributed energy resources to a radial designed utility raise many significant concerns. The most significant issue facing anyone planning to install a DER technology is the interconnection of the device to the electric utility system and its system impacts. In the United States, common standards for interconnecting DER devices into the utility system do not currently exist, though IEEE standard 1547 is in progress.

The question is who – the Utility or small DG's or large DG's or only those DG's that specifically affect the reliability of the utility system – should address these impacts. The resulting variation of opinion between the Utility and the DG provider is a huge barrier to the goal of DG implementation. Some of the *System impacts* that raise eyebrows on the Utility end are:

(i) The current utility system is radially designed to have power flow from the utility through the transmission line down to the distribution network. Introduction of generation by connecting the DG will impact the reliability of the system and back-feed is a primary concern.

(ii) The Utility needs to see a system with the DG and without the DG.

(iii) Distributed generation can potentially support unintentional system islands, isolated from the remainder of the system.

(iv) The addition of DG may complicate protection schemes and associated control equipment. If not planned properly, this would result in lower reliability and power quality.

(v) The DG may contribute to a fault, should a fault occur on the Utility end and it does not trip, due to non detection of fault

On the other hand the DG provider has the following issues:

(i) Whether to allow pre-certification of DG equipment using product type tests?

(ii) Whether engineering analysis of T&D system reliability and safety is necessary for all DG projects?

(iii) The charges to set for interconnection and use of the T&D system

(iv) Application and enforcement of the guideline requirements.

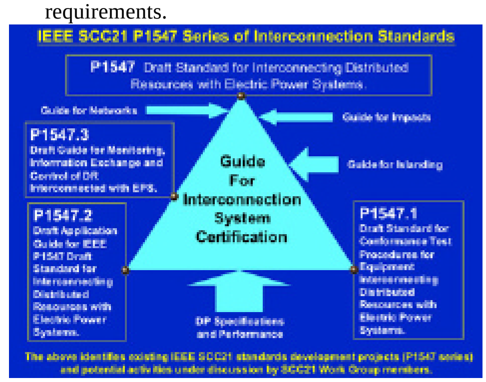

Figure 7: IEEE P1547 Interconnection Standards

There exists a clear solution for each concern raised by the Utility and the DG provider. What needs to be clear is better understanding by the Utility and DG, of each other's systems. Through proper strategy and planning, DG can greatly help the grid at the choking points and generation shortages without causing financial or safety problems. One of the most notable national efforts in the development of interconnection standards comes from the (IEEE). In 1999, under the organization's Standards Coordinating Committee 21 (SCC21), the IEEE formed working group P1547 to establish common practices for the grid interconnection of DER. The standard is titled "Standard for Interconnecting Distributed Resources with Electric Power Systems". It is a consensus standard that contains specific requirements related to performance, operation, testing, safety, and maintenance of interconnections between distributed resources and other electric power systems. Figure 7 shows the potential activities under discussion for the IEEE P1547 series.

- **Siting, permitting and environmental regulation:** Zoning, air & water use permits, comprehensive environmental plan approval, and other regulatory processes can both delay and increase the costs of DG projects. These issues typically relate to site-specific concerns. DG technologies are not covered in national building, electrical, and safety codes. The codes do address photovoltaic; but local code and zoning officials are typically not familiar with these technologies. Environmental regulations are not currently administered to give credit for the overall pollution reduction effects of high efficiency DG technologies.
- **Access, Metering and Dispatch:** These issues determine whether to allow DG access to the grid, and if so, how to meter and pay for access. DG installers often feel they pay too much while Discos (Distribution Companies) feel their costs are not being covered.

  A more level playing field can be established when the benefiting party pays incurred costs. As DG customers use the T&D system in new ways, for instance, being connected to the grid for either supplemental or backup power, new methods of assessing cost responsibility need to arise.
- **Current business models and practices:** Existing business practice and business models often reflect the old regulated electricity industry dominated by vertically integrated utilities and central station power plants. New business models are needed to capture the values of non-utility owned distributed power in delaying or avoiding transmission and distribution system upgrades, the use of distributed power for ancillary services and for improving system reliability, power quality and reducing line losses. New competitive business models need to be developed that will allow the realization of full economic value of distributed power in competitive markets.

  Other issues include:

  - Current regulations do not recognize the overall energy efficiency of DG technologies or credit the emissions avoided.
  - DG facilities fall into several tax categories, with depreciation periods far longer than comparable equipment.
  - Depreciation schedules for DG investments vary from 5 to 39 years depending on system ownership, and frequently don't reflect the true economic lives of the equipment.

VIII. Conclusions

Growing popularity of DG is comparable to the historical evolution of computers. Whereas we once relied solely on mainframe computers with outlying workstations that had no processing power, we now rely on a small number of servers networked with a larger number of desktop PCs, all of which help to meet the information processing demands of the end users. And just as the smaller size and lower cost of computers has enabled individuals to buy and run their own computing power, similar trend in DG technologies is enabling individual consumers to purchase and run their own power systems. Experts are confident that significant DG capacity will be installed if the barriers are removed based on following policy responses:

(i) Identify opportunities for implementation of output-based regulation that judge emission standards on the usable energy produced rather than on the fuel burned. Since DG systems use fuel efficiently, they are favored by this regulatory approach. Give credit for the substantial T&D savings of onsite DG. EPA already has issued such guidelines for utility generation. EPA should educate and assist states regarding implementing this environmental permitting approach.

(ii) The Federal Energy Regulatory Commission (FERC) should circulate & promote a national interconnection standard. It should also develop guidelines for purchase of backup power for DG facilities at fair and reasonable terms. States should implement interconnect and access rules favorable to DG, facilitate siting and permitting, cost-share DG feasibility studies, and review state facilities for DG opportunities.

(iii) Address issues of utility access & exit fees. A national restructuring bill can address these barriers. It will be necessary, to make the case for DG on a state-by-state basis.

(iv) Standardize net metering, which allows the meters for customers with DG facilities to run backwards when the DGs are producing excess energy to offset their consumption over a billing period. This offset means that users receive retail prices for the excess electricity generated. Without net metering, the provider purchases the excess power at a rate much lower than the retail rate.

(v) To encourage power system efficiency maximization and the rapid deployment of innovative DG technologies, equipment depreciation tax life should be standardized and made similar to comparable industrial equipment.

(vi) Congress should enact tax credits to encourage DG systems. The IRS should set a depreciation schedule for DG assets at 7 years, which reflects the true technical and economic life of most systems.

(vii) Set national DG targets and deadlines for action. Such goals motivate policymakers to consider the impacts of policy alternatives.

(viii) DOE should support educational and technical assistance efforts by state and regional initiatives to identify and implement DG at appropriate sites.

(ix) EPA should establish an expedited permitting process for DG applications

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