EPRI

technical update

Integrating Distributed Generation Into the Electric Distribution System

Distributed Resources: Information for Business Strategies

Introduction

Distributed generation (DG), when properly applied, can provide a number of benefits for utilities and end use electric customers. These potential benefits are well documented and include financial savings, improved voltage stability, increased reliability, and reduced emissions. However, if distributed generation systems are not properly installed and integrated with the electric power system, their potential value may be completely negated. This document explains the rationale behind utility interconnection standards, and thus hopes to promote safe, quick and reliable interconnection. General guidelines and recommendations are provided to assure successful electrical integration of a distributed resource.

The electric transmission and distribution system has been traditionally designed to operate as a "one-way" power flow system, with centralized plants feeding out to a variety of power usage points. Problems can arise when DG is connected to the distribution system and can send power through the system in the opposite direction. Even when the DG is designed to not export power back to the utility side, the problems can still occur due to the near-instantaneous flow of electrons in an interconnected system. The primary issues are system protection, personnel safety and voltage quality. These problems, which can impact the utility system or the DG, include voltage regulation, unintended tripping of protective devices, overvoltages, and various power quality impacts. These problems are not hypothetical—they have been well documented for at least fifteen years, most notably the undesirable interactions of the electric power system and uninterruptible power supplies with backup generators at mission critical facilities, variable speed drives, and programmable controllers. Fortunately, advances in power conditioning, protection and interconnection hardware and software technologies are making it easier for the power grid to accept increasing amounts of distributed generation.

To facilitate safe and reliable electrical interconnections, this document describes problems that can occur due to incorrect installation as well as the specific solutions for each of these topics:

- DG and Power System Protection
- Grounding and Interconnection Transformers
- Voltage Regulation Impacts

Incompatibilities Between the Utility Power System and Distributed Generation

The impact of a DG unit on the power distribution system can be either positive or negative depending on where and when the unit is operated. Ideally, an electric distribution company would want to place a distributed generator on the power system where it could support peak loading patterns and the voltage needs of the circuit. The electric company would typically conduct a rigorous engineering analysis to determine both the benefits and the potential impacts on other power system components. The electric company would then operate the unit when the largest benefit would be achieved. The protection devices used would be of the same premium quality and cost as components used in the rest of the electrical system.

When end users are installing and operating DG for their own economic reasons, it is not difficult to comprehend how these installations may end up quite different from what the utility would choose: the location would not necessarily provide the best peak loading or voltage support; there would not necessarily be a strong incentive to coordinate the designs of grounding and protective schemes of the DG with the power system; the timing of operation of the DG would not necessarily occur when the distribution circuit most needed power; and the quality of the DG protective devices may not be up to utility grade reliability standards. It is a difficult job balancing the interests of individual customers who want to benefit from DG against the interests of the remaining customers on the distribution circuit who want low cost and reliable power.

Figure 1 shows how DG may end up at multiple locations throughout a distribution system. Third party aggregators who dispatch numerous customer-sited generators to sell into power markets based only on price signals could cause problems for the utility system operator.

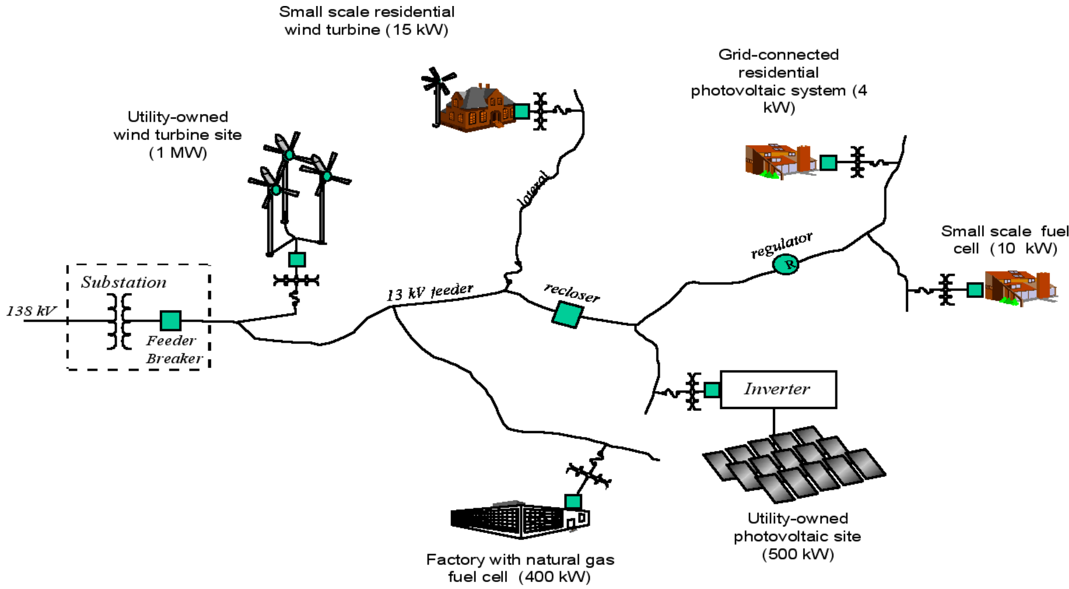

Figure 1. A Distribution System of the Future May Have DG at Many Different Points Within the System With Many Different Owners.

Nevertheless, safe and reliable DG installations can be achieved when consideration is given to the topics detailed in the following sections of this document.

System Protection

System protection requires that the DG follow safe and reliable interconnection and operation practices, including coordination with the circuit breaker settings, recloser practices and fusing of the utility distribution system. When integrated correctly, the DG will be available during normal utility system conditions and safely disconnect from (and reconnect with) the utility system when the need arises. When the utility system is not available or is under repair or maintenance, any distributed generation on the system must be disconnected and/or isolated from the grid so that the utility repair personnel are not unknowingly exposed to energized circuits. For synchronous and induction generators, this is typically accomplished with a relay that opens the circuit connection to the utility.

Protective Relays

For synchronous and induction generators, a relay must be supplied that will open the circuit connection to the utility when a fault occurs or when voltage and frequency parameters go outside of preselected thresholds. This relay may also be required to provide synchronizing capability if the DG device is to operate in parallel with the utility power system. The preferred specification should be what is referred to as a "utility grade" relay that meets ANSI/IEEE surge withstand capabilities, has high accuracy in pickup and time settings, and has a testable interface. Use of low cost, commercial/industrial grade motor protection relays is discouraged.

For inverter based grid connections, the inverter can perform the protection functions, but EPRI recommends that the unit have a testable interface to confirm the protective settings. UL 1741 provides guidelines on the use of "type tested" inverters for DG units that are directly connected to the electric power system. If islanding of loads is desired, a separate relay will be required to disconnect and isolate the DG and the loads from the utility system.

Anti-Islanding Protection

Islanding is a situation in which the DG and a portion of the power system are isolated and continue to serve loads. This condition can be either intentional or unintentional. Key dangers of unintentional islanding include:

- The islanded power system will drift out of phase with the utility power frequency and can be damaged upon reconnection
- Downed power conductors may remain energized causing a personnel safety hazard
- Unless the islanded DR is sufficiently sized to supply the islanded loads, frequency and voltage stability problems may be experienced
- Capacitor banks on the islanded section of the circuit may create a damaging overvoltage (or ferroresonance) condition that is not present when the full circuit is energized.

EPRI and IEEE standard 1547 recommend that DG devices are installed with anti-islanding protection. If islanding is desired, further load and power system coordination studies are recommended to insure that the DG is able to support the islanded load and maintain adequate voltage and frequency regulation.

Coordination With Fault Protection Settings of the Distribution System

Coordination of DG with the distribution system depends on the type of system serving the DG location. There are two primary types of distribution systems, and a few subcategories under the two main types, each having unique protective schemes. These main types are the radial system and the network system.

Radial Systems—The radial system is structured so that when a fault or a short circuit occurs, one or more protective devices will open to either clear the fault, or isolate the section of the circuit that has been affected. The normal utility practice of using protective devices to clear faults and minimize the number of customers experiencing service interruptions depends on real power flowing in one direction, from the power generator to the substation, and then to the feeder circuits and the loads. Placing a distributed generator downstream of the substation may (depending on the size of the DG) "fool" the circuit protective devices such that they are no longer able to safely or reliably perform their functions.

As an example, a fuse located on a lateral line off of a main feeder circuit as shown in Figure 2 may be coordinated with the substation circuit breaker in such a way that the breaker opens prior to the fuse melting. This is a very common fuse saving practice. Installation of a DG device will contribute to the fault current that passes through the fuse. If a fault occurs downstream of the fuse and the DG device is located at a point upstream of the fuse, the additional current contribution from the DG may cause the fuse to melt before the substation breaker has a chance to operate. This would cause a sustained interruption for all customers downstream of the fuse. The DG device would decrease power system reliability. As a second example, if the DG device were located downstream of the fuse and the same fault occurred, the breaker at the substation may be unable to sense the fault current, and thus neither it nor the fuse would operate quickly enough to prevent damage to the DG or to circuit hardware. Many other scenarios are possible where reliability can be decreased, or where misoperation of protective devices may occur when DG is installed. That is why it is extremely important to coordinate the installation effort with the serving power company.

Networks—Network distribution systems are typically found in metropolitan locations such as New York City, San Francisco, Chicago and other large urban areas. In a network system power is fed through a group of transformers that are interconnected in a grid fashion on the secondary side. This grid arrangement necessitates the use of network protector devices to keep fault currents from flowing back from the secondary to the primary circuits. Network protectors are relays that can sense reverse current flow and quickly open to limit this condition. Because DG devices can cause the network protectors to open and create an unintentional island, the use of DG must be limited and very closely coordinated with the utility company. Currently, the best practices for using DG in networked distribution systems are to either limit the size of the DG to less than the lightest loading condition for the facility where the DG is installed, or to intentionally isolate the facility or a portion of the facility loads from the utility system when the DG is operating.

Transformers and Grounding

Grounding is a crucial design characteristic of every power distribution system—impacting its safety and protection, as well as how loads and generators can be connected to it. DG must be configured and operated in a manner that is compatible with the grounding design of the distribution system. Failure to achieve compatibility can lead to serious safety problems or damage to customer loads and or utility company equipment. Proper grounding analysis of DG will

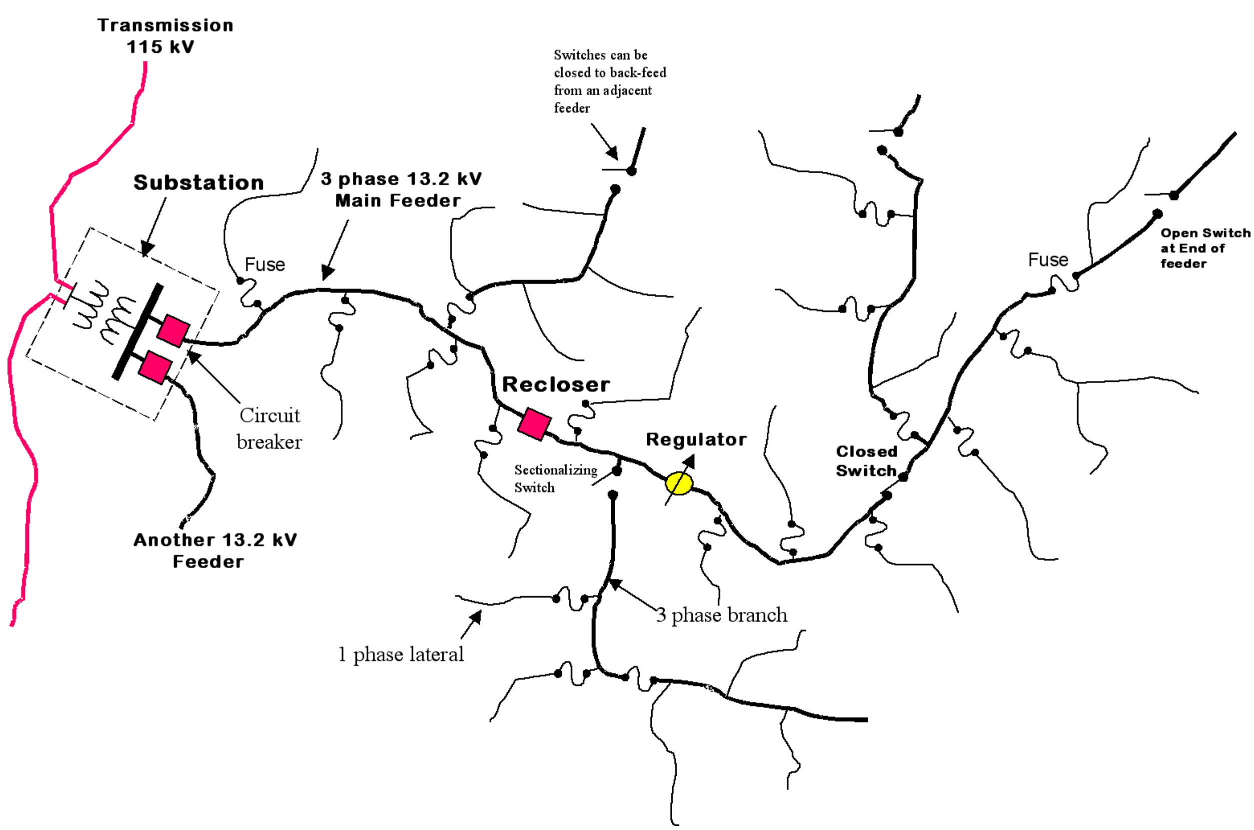

Figure 2. Example of the Fault Protection on a Radial Distribution System.

Primary Distribution Type	Secondary Distribution Type	DG Grounding Practice
Three-wire, ungrounded system or high-impedance grounded system	Four-wire, Grounded	DG should be ungrounded or high -impedance grounded with respect to the primary, and effectively grounded* with respect to the secondary
	Three-wire, Ungrounded	DG should be ungrounded or high -impedance grounded with respect to the primary and secondary system
Four-wire multi-grounded neutral system	Four-wire, Grounded	DG should be effectively grounded with respect to the primary and the secondary system
	Three-wire, Ungrounded	DG should be effectively grounded with respect to the primary system and ungrounded or high -impedance grounded with respect to the secondary system *

Table 1. Grounding Recommendations for Distributed Generation

* Effective grounding is accomplished by solidly bonding the neutral conductor to the grounding network for the power system such that the neutral conductor remains at ground potential during fault conditions. With an effectively grounded system, a phase-to-ground fault should not cause a voltage rise on unfaulted phases exceeding 125% of the nominal line to neutral system voltage.

ensure compatibility with grounding for both the primary and secondary power system. This analysis must include the following:

- The generator winding configuration or inverter arrangement and its grounding point
- The interface transformer configuration at the DG location
- Grounding methods used on the primary power system at the DG location
- Grounding methods used on the secondary power system at the DG location

Depending upon the area of the country and the serving utility company, the distribution configuration may be either an ungrounded three-wire system or the more common four-wire grounded neutral system. Separate and independent of the primary configuration, the options for the secondary are also either three wire ungrounded (delta) or the more common four wire grounded (wye).

For grounded secondary configurations, the first step to insuring compatibility of the DG device with the power system grounding configuration is to design a system that has the ability to first, protect personnel and equipment safely by tripping the upstream circuit breaker, and second, to provide "effective grounding" in order to limit serious overvoltages on unfaulted phases. This limit should be no more than 125% of the system nominal voltage between any phase and the neutral conductor. If the wrong grounding configuration is chosen, a fault could produce 173% of the nominal phase-to-phase voltage, which would damage other connected equipment and cause lightning arrestor failures.

For ungrounded (delta) secondary systems, the DG device must be ungrounded or must be impedance grounded, and ground fault sensors must be used to alert onsite personnel to any ground fault conditions. A summary of EPRI grounding recommendations for the various transformer configurations is found in Table 1.

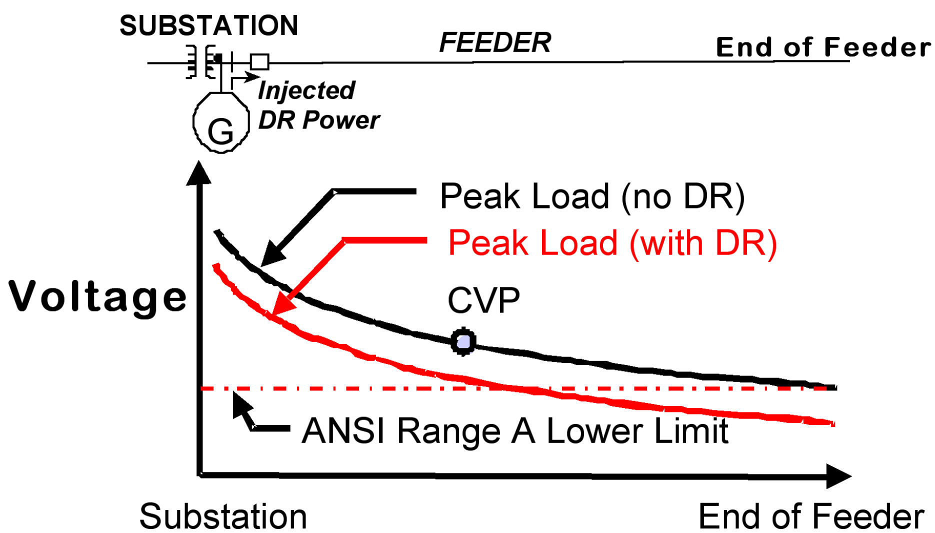

Figure 3. Voltage Profiles With and Without a Large Amount of Distributed Resources Connected at the Substation. CVP is the Voltage Control Point on the Feeder.

Voltage Regulation Impacts of Distributed Generation

DG can create unusually high voltage (or, in some cases, unusually low voltage) if proper care and consideration are not given to the size of the DG and the distribution system circuit characteristics at the installation location. When real power is injected into the power system, the voltage at the point of current injection will increase, in proportion to the size of the DG (either individual or in aggregate). This voltage rise also depends on the circuit impedance at the point of injection, phase angle of the current with respect to the system voltage and impacts of any regulating devices on the circuit. The opposite effect (low voltage) can occur at the end of a long radial feeder if the DG point of injection is near a substation voltage regulator. Figure 3 shows an example of the impact on voltage across the length of a feeder when DG is present at or near a substation.

These voltage upsets can impact many customers and facilities on the circuit. For a small amount of DG, the voltage rise is typically not a great concern. As a general rule of thumb, any time the DG steady state current rating is greater than one percent of the fault current capacity of the circuit at the point of DG connection, coordination with the utility and more study is recommended. It is also recommended that DG be monitored after installation to insure that voltage variations are within ANSI/IEEE C84.1 steady state voltage limits, and to define the steady state voltage window that will be experienced at the point of connection.

Summary and Recommendations

This document provides a summary of the major issues and best practices for integration of DG into the electric power system. DG integration is not a simple issue in particular when the size of the DG (either one device or a large aggregation of DG) becomes more than five or ten percent of the circuit capacity or when the DG is installed at a point very far from the substation. When properly integrated, DG can have a positive impact on the power system. The key to success is integrating the DG in a fashion that does not degrade the safety, reliability, quality of delivered power or efficiency of the power system. Interconnection standards such as IEEE 1547 and other state and federal guidelines are available or in development and provide guidelines in this area. While this document does not cover every scenario, a summary of generally recommended practices to assure a safe and effective DG integration follows.

Protective Relays

For synchronous and induction generators, a relay must be supplied that will open the circuit connection to the utility when a fault occurs or when voltage and frequency parameters go outside of preselected thresholds. This relay may also be required to provide synchronizing capability if the DG device is to operate in parallel with the utility system. The preferred relays should be "utility grade," meet ANSI/IEEE surge withstanding capabilities, have high accuracy in pickup and time settings, and have a testable interface. Use of low cost commercial/industrial grade motor protection relays is discouraged.

For inverter based grid connections, the inverter can perform the protection functions, but it is recommended that the unit have a testable interface to confirm the protective settings. UL 1741 provides guidelines on the use of "type tested" inverters for DG units that are to be directly connected to the electric power system. If islanding of loads is desired, a separate relay will be required to disconnect and isolate the DG and the loads from the utility system.

Utility Protective Device Coordination

For Radial Distribution Systems

There are many scenarios where a DG unit may contribute enough fault current to the circuit to compromise the protective device coordination for the feeder. If the DG steady state current rating is greater than one percent of the fault current capacity of the circuit at the point of DG connection, coordination with the serving utility is advisable.

For Network Distribution Systems

Always coordinate the installation effort with the serving power company. Currently, the best practices for using DG in networked distribution systems are to either limit the size of the DG to less than the lightest loading condition for the facility, or to intentionally isolate the facility or a portion of the facility loads from the utility system when the DG is operating

Anti Islanding Relay

The recommended practice for DG devices is to install them with anti-islanding protection. If islanding is desired, further load and power system coordination studies are recommended to insure that the DG is able to support the islanded load and maintain adequate voltage and frequency regulation.

Grounding of DG

DG must be grounded in a manner that is compatible with the grounding of the primary and secondary distribution system. For recommended grounding configurations refer to Table 1.

Voltage Variation

Similar to the protective device coordination recommendation, any time the DG steady state current rating is greater than one percent of the fault current capacity of the circuit at the point of DG connection, coordination with the utility and more study is recommended to insure that the voltage variation due to the DG is within acceptable limits. It is also recommended that DG be monitored after installation to insure that voltage variations are within ANSI/IEEE C84.1 limits, and to define the steady state voltage window that will be experienced at the point of connection.

Further Information

Integrating Distributed Resources into Electric Utility Distribution Systems: EPRI White Paper, EPRI, Palo Alto, CA: December, 2001. 1004061.

IEEE P1547 Draft Standard for Interconnecting Distributed Resources with Electric Power Systems. (Not yet available in final form. For additional information go to the 1547 website at http://grouper.ieee.org/groups/scc21/1547/1547_index.html).

For More Information

D. Herman, EPRI Project Manager, phone: 650.855.1057,
email: dherman@epri.com

Organization That Prepared This Document

EPRI PEAC
942 Corridor Park Blvd.
Knoxville, TN 37932

Principal Investigator
D. Dorr

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304-1395 USA
PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com