Distributed Generation and Power Quality

Martin Kanálik, Marek Kurajda

ABSTRACT

Many involved in power quality have also become involved in distributed generation (DG) because there is considerable overlap in the two technologies. As the name implies, DG uses smaller-sized generators than does the typical central station plant. They are distributed throughout the power system closer to the loads. The term smaller-sized *can apply to a wide range of generator sizes. Because this paper is primarily concerned with power quality of the primary and secondary distribution system, the discussion of DG will be confined to generator sizes less than 10 MW. Generators larger than this are typically interconnected at transmission voltages where the system is designed to accommodate many generators.*

1. INTRODUCTION

Renewable sources often produce power and voltage varying with natural conditions (wind speed, sun light etc.,) and grid connection of these sources is essential if they are ever to realize their potential to significantly alleviate the present day problems of atmospheric pollution and global warming. However, electric utility grid systems cannot readily accept connection of new generation plant without strict conditions placed on voltage regulation due to real power fluctuation and reactive power generation or absorption, and on voltage waveform distortion resulting from harmonic currents injected by nonlinear elements of the plant.

For more than 7 decades, the norm for the electric power industry in developed nations has been to generate power in large, centralized generating stations and to distribute the power to end users through transformers, transmission lines, and distribution lines. This is often collectively referred to as the "wires" system in DG literature.

The normal distribution system delivers electric energy through wires from a single source of power to a multitude of loads. Thus, several power quality issues arise when there are multiple sources. Will be improve the power quality or will it degrade the service end users and come to expect? There are arguments supporting each side of this question, and several of the issues that arise are examined here.

2. PERSPECTIVES ON DG BENEFITS

One key to understanding the DG issue is to recognize that there are multiple perspectives on every relevant issue. To illustrate, we discuss the benefits of DG from three different perspectives.

1. End-user perspective. This is where most of the value for DG is found today. End users who place a high value on electric power can generally benefit greatly by having backup generation to provide improved reliability. Others will find substantial benefit in high-efficiency applications, such as combined heat and power, where the total energy bill is reduced. End users may also be able to receive compensation for making their generation capacity available to the power system in areas where there are potential power shortages.

2. Distribution utility perspective. The distribution utility is interested in selling power to end users through its existing network of lines and substations. DG can be used for transmission and distribution (T&D) capacity relief. In most cases, this application has a limited life until the load grows sufficiently to justify building new T&D facilities. Thus, DG serves as a hedge against uncertain load growth. It also can serve as a hedge against high price spikes on the power market (if permitted by regulatory agencies).

3. Commercial power producer perspective. Those looking at DG from this perspective are mainly interested in selling power or ancillary services into the area power market. In the sense that DG is discussed here, most units are too small to bid individually in the power markets. Commercial aggregators will bid the capacities of several units. The DG may be directly interconnected into the grid or simply serve the load off-grid. The latter avoids many of the problems associated with interconnection but does not allow the full capacity of the DG to be utilized.

3. WIND TURBINES

Wind generation capacity has been increasing rapidly and has become cost competitive with other means of generation in some regions. A common implementation is to group a number of wind turbines ranging in size from 700 to 1200 kW each into a "wind farm" having a total maximum capacity range of 200 to 500 MW. One example is shown in Fig. 1. Such large farms are interconnected to the transmission system rather than the distribution system. However, smaller farms of 6 to 8 MW have been proposed for applications such as ski resorts, and they would be connected directly to distribution feeders.

The chief power quality issue associated with wind generation is voltage regulation. Wind generation tends to be located in sparsely populated areas where the electrical system is weak relative to the generation capacity. This results in voltage variations that are difficult to manage. Thus, it is sometimes impossible to serve loads from the same feeder that serves a wind farm.

There are three main classes of generator technologies used for the electrical system interface for wind turbines:

1. Conventional squirrel-cage induction machines or wound-rotor induction machines. These frequently are supplemented by switched capacitors to compensate for reactive power needs.
2. Doubly fed wound-rotor induction, machines that employ power converters to control the rotor current to provide reactive power control.
3. Non-power frequency generation that requires an inverter interface.

Fig. 1 Wind farm in the midwestern United States. *(Courtesy of Enron Corp.)*

4. PHOTOVOLTAIC SYSTEMS

The recent power shortages in some states and the passage of net metering legislation has spurred the installation of rooftop photovoltaic solar systems. Figure 2 shows a large system on a commercial building in California. A typical size for a residential unit would be between 2 and 6 kW. Once installed, the incremental cost of electricity is very low with the source of energy being essentially free while it is available.

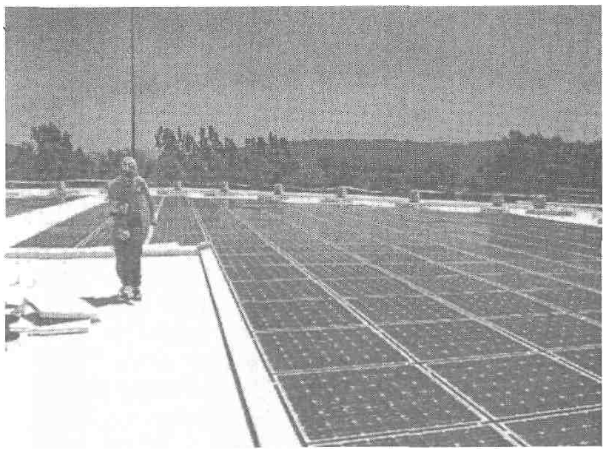

Figure 2 Rooftop photovoltaic solar system. *(Courtesy of PowerLight Corporation.)*

However, the first cost is very substantial even with buy-down incentives from government programs. Installed costs currently range from $5000 to $20,000/kW. Despite this high cost, photovoltaic solar technology is favored by many environmentalists and installed capacity can be expected to continue growing.

Photovoltaic solar systems generate dc power while the sun is shining on them and are interfaced to the utility system through inverters. Some systems do not have the capability to operate stand-alone - the inverters operate only in the utility-interactive mode and require the presence of the grid.

5. POWER QUALITY ISSUES

The main power quality issues affected by DG are

5.1 *Sustained interruptions.* This is the traditional reliability area. Many generators are designed to provide backup power to the load in case of power interruption. However, DG has the potential to increase the number of interruptions in some cases.

Much of the DG thafeis already in place was installed as backup generation. The most common technology used for backup generation is diesel gensets. The bulk of the capacity of this form of DG can be realized simply by transferring the load to the backup system. However, there will be alllitional power that can be extracted by paralleling with the power system. Many DG installations will operate with better power quality while paralleled with the utility system because of its large capacity However, not all backup DG can be paralleled without great expense.

Not all DG technologies are capable of significant improvements in reliability. To achieve improvement, the DG must be capable of serving the load when the utility system cannot.

5.2 *Voltage regulation.* This is often the most limiting factor for how much DG can be accommodated on a distribution feeder without making changes.

It may initially seem that DG should be able to improve the voltage regulation on a feeder. Generator controls are much faster and smoother than conventional tap-changing transformers and switched capacitor banks. With careful engineering, this can be accomplished with sufficiently large DG. However, there are many problems associated with voltage regulation. In cases where the DG is located relatively far from the substation for the size of DG, voltage regulation issues are often the most limiting for being able to accommodate the DG without changes to the utility system.

It should first be recognized that some technologies are unsuitable for regulating voltages. This is the case for simple induction machines and for most utility interactive inverters that produce no reactive power. Secondly, most utilities do not want the DG to attempt to regulate the voltage because that would interfere with utility voltage regulation equipment and increase the chances of supporting an island.

5.3 *Harmonics.* There are harmonics concerns with both rotating machines and inverters, although concern with inverters is less with modern technologies.

There are many who still associate DG with bad experiences with harmonics from electronic power converters. If thyristor-based, line-com-mutated inverters were still the norm, this would be a large problem. Fortunately, the technologies requiring inverters have adopted the switching inverters like the one described previously in this chapter. This has eliminated the bulk of the harmonics problems from these technologies.

One problem that occurs infrequently arises when a switching inverter is installed in a system that is resonant at frequencies produced by the switching process. The symptom is usually high-frequency hash appearing on the voltage waveform. The usual power quality complaint, if any, is that clocks supplied by this voltage run fast at times. This problem is generally solved by adding a capacitor to the bus that is of sufficient size to shunt off the high-frequency components without causing additional resonances.

Harmonics from rotating machines are not always negligible, particularly in grid parallel operation. The utility power system acts as a short circuit to zero-sequence triplen harmonics in the voltage, which can result in surprisingly high currents. For grounded wye-wye or delta-wye service transformers, only synchronous machines with 2/3 pitch can be paralleled without special provisions to limit neutral current. For service transformer connections with a delta-connected winding on the DG side, nearly any type of three-phase alternator can be paralleled without this harmonic problem.

5.4 *Voltage sags.* This a special case because DG may or may not help.

The most common power quality problem is a voltage sag, but the ability of DG to help alleviate sags is very dependent on the type of generation technology and the interconnection location. Figure 3 illustrates a case in which DG is interconnected on the load side of the service transformer. During a voltage sag, DG might act to counter the sag. Large rotating machines can help support the voltage magnitudes and phase relationships. Although not a normal feature, it is conceivable to control an inverter to counteract voltage excursions.

The DG influence on sags at its own load bus is aided by the impedance of the service transformer, which provides some isolation from the source of the sag on the utility system. However, this impedance hinders the ability of the DG to provide any relief to other loads on the same feeder. DG larger than 1 MW will often be required to have its own service transformer. The point of common coupling with any load is the primary distribution system. Therefore, it is not likely that DG connected in this manner will have any impact on the voltage sag characteristic seen by other loads served from the feeder.

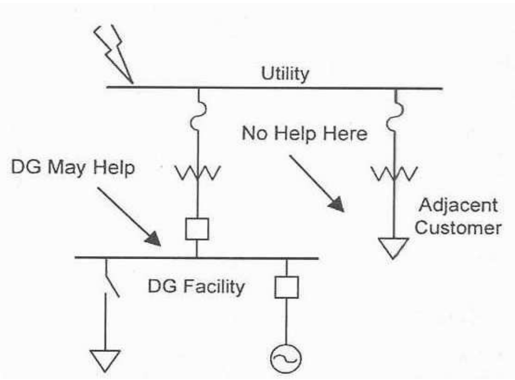

Figure 3 DG may help reduce voltage sags on local facility bus, but impedance of interconnection transformer inhibits any impact on adjacent utility customers.

6. CONCLUSSION

Voltage regulation problems are often the first to appear, followed by interference with the utility fault-clearing process, which includes concerns for islanding.

Changes can be made to accommodate nearly any amount of DG. As the amount of DG increases, the simple, low-cost distribution system design must be abandoned in favor of a more capable design. It will almost certainly be more costly, but engineers can make it work. Deciding who pays for it is another matter.

In a future of massively distributed generation, as some see it, communications and control will be key. Today, most of the control of distribution systems is accomplished by local intelligence operating autonomously. Systems with high penetrations of DG would benefit greatly from fast, interconnected communications networks. This is one technology shift that must accompany the spread of DG if it is to be successful in contributing to reliable, high-quality electric power.

7. REFERENCES

[1] Dugan R. C. – McGranaghan M. F. – Santoso S. – Beaty H. W.: Electric power systems quality, second edition, McGraw Hill, 2003, New Yourk, ISBN 0-07-138622-X

[2] IEEE Standard P1547, Distributed Resources Interconnected with Electric Power Systems,

[3] www.lpqi.org, Leonardo Power Quality Initiative

[4] Chen Z.: „Grid Power Quality with Variable Speed Wind Turbines“, IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 16, NO. 2, JUNE 2001

Authors address:

Ing. Martin Kanálik
Department of Electric Power Engineering
Faculty of Electrical Engineering & Informatics
Technical University of Košice
Mäsiarska 74
041 20 Košice
SLOVAK REPUBLIC
E-mail: Martin.Kanalik@tuke.sk
http://www.tuke.sk/kanalik

Ing. Marek Kurajda
Department of Electric Power Engineering
Faculty of Electrical Engineering & Informatics
Technical University of Košice
Mäsiarska 74
041 20 Košice
SLOVAK REPUBLIC
E-mail: Martin.Kanalik@tuke.sk
http://www.tuke.sk/kanalik