Benefits of Power Electronic Interfaces for Distributed Energy Systems

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***Abstract*—With the increasing use of distributed energy (DE) systems in industry and its technological advancement, it is becoming more important to understand the integration of these systems with the electric power systems. New markets and benefits for DE applications include the ability to provide ancillary services, improve energy efficiency, enhance power system reliability, and allow customer choice. Advanced power electronic (PE) interfaces will allow DE systems to provide increased functionality through improved power quality and voltage/volt–ampere reactive (VAR) support, increase electrical system compatibility by reducing the fault contributions, and flexibility in operations with various other DE sources, while reducing overall interconnection costs. This paper will examine the system integration issues associated with DE systems and show the benefits of using PE interfaces for such applications.**

***Index Terms*—Distributed energy (DE), distributed generation (DG), fault current, interconnection, interface, inverter, microgrid, power electronics (PE), power quality.**

I. Introduction

DISTRIBUTED energy (DE) systems, also called distributed generation (DG), are energy systems located at or near the point of use. Typically ranging from 1 kW to 10 MW, they can provide both electricity and in some cases heat. There are a wide variety of potential benefits to DE systems both to the consumer and the electrical supplier that allow for both greater electrical flexibility and energy security [1]. For the customer, these benefits include: reduced price volatility, greater reliability, and improved power quality. There are many potential benefits for the energy supplier, such as released line capacity, reduced transmission and distribution congestion, grid investment deferment and improved grid asset utilization, and the ability of the DE system to provide ancillary services, such as voltage support and stability, volt–ampere reactive (VAR) support, and contingency reserves. Depending on economics, there are a wide variety of applications for DE systems: backup and emergency power, base load power, and peaking power in addition to offering a combined heat and power (CHP) option if the customer has a use for the thermal heat generated by the DE system.

In order to increase the usefulness of DE systems and reduce potential impacts, power electronic (PE) interfaces can be used to integrate DE with the existing electrical power system. PE interfaces offer unique capabilities over traditional interconnection technologies. As the price of PE and associated control systems decrease, these types of interconnection interfaces, along with their benefits, will become more prevalent in use with all types of DE systems. This paper examines system integration issues and discusses the benefits of using PE interfaces for a variety of DE applications.

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II. Types of DE Systems

DE systems may be powered by either fossil or renewable fuels. This section summarizes the most common types of DE systems on the market. More thorough discussions on the details of each DG technology are available on [2] and [3].

A. Reciprocating Internal Combustion Engines

Reciprocating internal combustion (IC) engines burn fossil fuel to convert chemical (or heat) energy to mechanical energy from moving pistons. The pistons then spin a shaft and convert the mechanical energy into electrical energy via an electric generator. Those engines can be of either spark ignition type using natural gas, propane, or gasoline, or compression types that use diesel fuel or heavy oil. The electric generator is usually synchronous or induction type, and is typically connected directly to the electric power system without any additional interconnection device.

B. Gas Turbines

Gas turbines, like IC engines, mix fossil fuel with air to create thermal (or heat) energy. High temperature, high-pressure air is the medium of heat transfer and air is allowed to expand in the turbine; thereby converting the heat energy into mechanical energy that spins a shaft. The shaft is connected to a series of reduction gears that spin a synchronous generator that is directly connected to the electric power system. Again for large systems, there is not an additional interconnection device.

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C. Microturbines

Microturbines work on a very similar principle to gas turbines as discussed earlier. Microturbines can burn a variety of fuels, including natural gas, gasoline, diesel, kerosene, naphtha, alcohol, propane, methane, and digester gas. The majority of commercial devices presently available use natural gas as the primary fuel. In a typical microturbine, a permanent magnet generator (PMG) spins at high speeds (80 000 r/min is typical) and produces electricity at a very high frequency. Hence, the generator cannot be connected directly to the grid. The high-frequency voltage is rectified to dc and a PE-based inverter is then used to convert the dc electricity to ac power compatible with the electric power system.

D. Fuel Cells

Fuel cells work by the chemical reaction of combining hydrogen and oxygen to form electricity and water [4]. There are several different types of fuel cells currently available, including phosphoric acid, molten carbonate, solid oxide, and proton exchange membrane (PEM). Fuel cells produce dc power. This is again converted via an inverter to ac power that is compatible with the electric power system.

E. Photovoltaic Systems

Photovoltaic (PV) systems convert solar energy into electricity. PV modules produce dc power. Like fuel cells, the dc power is the converter into ac power compatible with the electric power system by a PE inverter.

F. Wind Systems

Wind turbines convert wind energy (kinetic or mechanical) into electrical energy. There are three basic types of wind turbine technology currently used for interconnecting with electric power systems. 1) In the first type called an induction machine, the wind turbine spins the rotor shaft of a standard cage-rotor induction generator connected directly to the grid without any PE interface. The induction machine requires VARs to operate. These can either be supplied by the utility power system or by capacitors connected at the machine terminals. These machines cannot deliver any reactive power. 2) The second type of design uses a double-fed induction generator (DFIG) and requires a wound-rotor design. In this case, power from the spinning rotor (at slip frequency) is collected via slip rings. Since this power is not produced at a voltage and frequency that is compatible with the electric power system, it is passed through a PE-based rectifier and inverter system, which transforms it into grid compatible ac power. This arrangement allows the generator stator winding to be undersized by 25%–30% with the PE making up the power difference from the rotor power. However, the cost of PE adds to the total cost of such a design. 3) The third type of wind turbine design uses a conventional or permanent magnet synchronous generator to convert the wind turbine power to a variable voltage, variable frequency output that varies with wind speed. A PE-based rectifier and inverter are then used to convert the full-rated output of the machine to power that is compatible with the electric power system. The last two designs (involving PE) allow the wind turbine to operate in a variable speed mode that can improve the overall wind power capture ability of the turbine.

G. Energy Storage

Energy storage technologies are classified according to the total energy, time, and transient response required for their operation. It is convenient to define storage capacity in terms of the time that the nominal energy capacity can cover the load at rated power. Storage capacity can be then categorized in terms of energy density requirements (for medium- and long-term needs) or in terms of power density requirements (for short and very short term needs). Energy storage enhances DE systems overall performance in three ways. First, it stabilizes and permits DE to run at a constant and stable output, despite load fluctuations. Second, it provides the ride through capability when there are dynamic variations of primary energy (such as those of sun, wind, and hydropower sources). Third, it permits DE to seamlessly operate as a dispatchable unit. Moreover, energy storage can benefit power systems by damping peak surges in electricity demand, countering momentary power disturbances, providing outage ride-through while backup generators respond, and reserving energy for future demand.

Battery systems store electrical energy in the form of chemical energy. There are a wide variety of battery technologies. Akhil and Kraft [5] gives a good description of battery types and Gyuk *et al.* [6] presents and overview of battery projects in the U.S. Batteries are dc power systems that require PE to convert the energy to and from ac power. Many utility connections for batteries have a bidirectional charger/inverter, which allows energy to be stored and taken from the batteries.

Supercapacitors, also known as ultracapacitors, are electrical energy storage devices, which offer high-power density and extremely high-cycling capability. Recent technology improvements enabled supercapacitors to be an interesting option for short-term high-power applications, although most research has focuses on automotive and traction drives, regenerative energy systems, and medical and telecommunication equipment [7], there have been some studies looking at the use of supercapacitors with wind systems [8].

Flywheel systems have recently regained consideration as a viable means of supporting critical load during grid power interruption because of their fast response compared to electrochemical energy storage. Advances in PE and digitally controlled fields have led to better flywheel designs that deliver a cost-effective alternative in the power quality market. Typically, an electric motor supplies mechanical energy to the flywheel and a generator is coupled on the same shaft that outputs the energy, when needed, though a PE converter. It is also possible to design a bidirectional PE system with one machine that is capable of motoring and regenerating operations.

III. Interconnection Interfaces

As briefly identified earlier, the electric output of DE systems can be connected to the electrical power system via three basic interconnection interfaces [9], [10].

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