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Distributed Generation

1.1 Introduction

Distributed generation (DG) is related with the use of small generating units installed at strategic points of the electric power system or locations of load centres [1]. DG can be used in an isolated way, supplying the consumer's local demand, or integrated into the grid supplying energy to the remainder of the electric power system. DG technologies can run on renewable energy resources, fossil fuels or waste heat. Equipment ranges in size from less than a kilowatt (kW) to tens of megawatts (MW). DG can meet all or part of a customer's power needs. If connected to a distribution or transmission system, power can be sold to the utility or a third party.

DG and renewable energy sources (RES) have attracted a lot of attention worldwide [2–4]. Both are considered to be important in improving the security of energy supplies by decreasing the dependency on imported fossil fuels and in reducing the emissions of greenhouse gases (GHGs). The viability of DG and RES depends largely on regulations and stimulation measures which are a matter of political decisions.

1.2 Reasons for DG

DG can be applied in many ways and some examples are listed below:

- It may be more economic than running a power line to remote locations.
- It provides primary power, with the utility providing backup and supplemental power.
- It can provide backup power during utility system outages, for facilities requiring uninterrupted service.

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- For cogeneration, where waste heat can be used for heating, cooling or steam. Traditional uses include large industrial facilities with high steam and power demands, such as universities and hospitals.
- It can provide higher power quality for electronic equipment.
- For reactive supply and voltage control of generation by injecting and absorbing reactive power to control grid voltage.
- For network stability in using fast-response equipment to maintain a secure transmission system.
- For system black-start to start generation and restore a portion of the utility system without outside support after a system collapse.

DG can provide benefits for consumers as well as for utilities. Some examples are listed below:

- Transmission costs are reduced because the generators are closer to the load and smaller plants reduce construction time and investment cost.
- Technologies such as micro turbines, fuel cells and photovoltaics can serve in several capacities including backup or emergency power, peak shaving or base load power.
- Given the uncertainties of power utility restructuring and volatility of natural gas prices, power from a DG unit may be less expensive than conventional electric plant. The enhanced efficiency of combined heat and power (CHP) also contributes to cost savings [5].
- DG is less capital intensive and can be up and running in a fraction of the time necessary for the construction of large central generating stations.
- Certain types of DG, such as those run on renewable resources or clearer energy systems, can dramatically reduce emissions as compared with conventional centralized large power plants.
- DG reduces the exposure of critical energy infrastructure to the threat of terrorism.
- DG is well suited to providing the ancillary services necessary for the stability of the electrical system.
- DG is most economical in applications where it covers the base load electricity and uses utility electricity to cover peak consumption and the load during DG equipment outages, i.e. as a standby service.
- DG can offset or delay the need for building more central power plants or increasing transmission and distribution infrastructure, and can also reduce grid congestion, translating into lower electricity rates for all utility customers.
- Smaller, more modular units require less project capital and less lead-time than large power plants. This reduces a variety of risks to utilities, including forecasting of load/resource balance and fuel prices, technological obsolescence and regulatory risk.
- DG can provide the very high reliability and power quality that some businesses need, particularly when combined with energy storage and power quality technologies.

- Small generating equipment can more readily be resold or moved to a better location.
- DG maximizes energy efficiency by enabling tailored solutions for specific customer needs such as combined heat and power systems.
- By generating power at or very near the point of consumption where there is congestion, DG can increase the effective transmission and distribution network capacity for other customers.
- DG can reduce customer demands from the grid during high demand periods.
- DG can provide very high-quality power that reduces or eliminates grid voltage variation and harmonics that negatively affect a customer's sensitive loads.
- DG may allow customers to sell excess power or ancillary services to power markets, thus increasing the number of suppliers selling energy and increasing competition and reducing market power.
- DG can reduce reactive power consumption and improve voltage stability of the distribution system at lower cost than voltage-regulating equipment.
- DG eliminates the need for costly installation of new transmission lines, which frequently have an environmental issue.
- DG reduces energy delivery losses resulting in the conservation of vital energy resources.
- DG expands the use of renewable resources, such as biomass cogeneration in the paper industry, rooftop solar photovoltaic systems on homes, and windmills further to improve energy resource conservation.
- DG offers grid benefits like reduced line loss and increased reliability [6]. From a grid security standpoint, many small generators are collectively more reliable than a few big ones. They can be repaired more quickly and the consequences of a small unit's failure are less catastrophic. DG eliminates potential blackouts caused by utilities' reduced margin of generation reserve capacity. Figure 1.1 shows the number of customers affected by major blackouts during the last four decades worldwide.

1.3 Technical Impacts of DG

DG technologies include engines, small wind turbines, fuel cells and photovoltaic systems. Despite their small size, DG technologies are having a stronger impact in electricity markets. In some markets, DG is actually replacing the more costly grid electricity. However, there are technical issues that deserve attention.

1.3.1 DG Technologies

No single DG technology can accurately represent the full range of capabilities and applications or the scope of benefits and costs associated with DG. Some of these technologies have been used for many years, especially reciprocating engines and gas turbines. Others, such as fuel cells and micro turbines, are relative

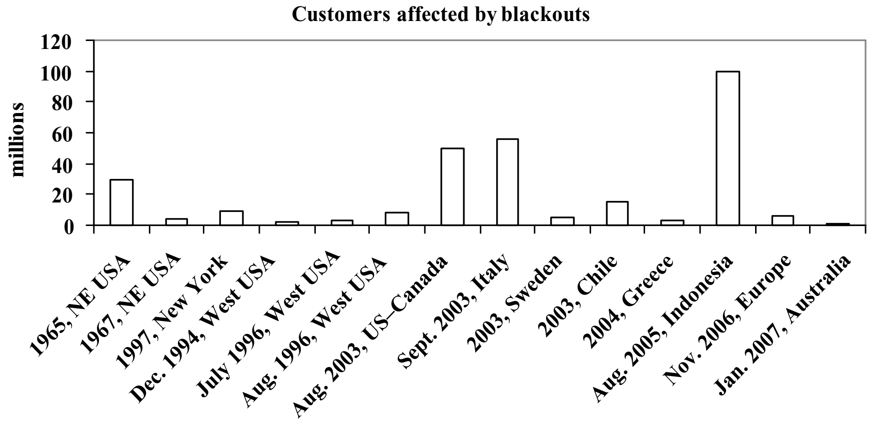

Figure 1.1 *Number of customers affected by major blackouts. Reproduced by permission of T.-F. Chan and L. L. Lai, 'Permanent-Magnet Machines for Distributed Power Generation: A Review' paper No. 07GM0593, IEEE 2007 General Meeting, Tampa, USA. Copyright ©(2007) IEEE + reference to publication, author*

new developments. Several DG technologies are now commercially available, and some are expected to be introduced or substantially improved within the next few years [7].

Reciprocating engines. Diesel and gas reciprocating engines are well-established commercial DG technologies. Industrial-sized diesel engines can achieve fuel efficiencies in excess of 40 % and are relatively low cost per kilowatt. While nearly half of the capacity was ordered for standby use, the demand for units for continuous or peak use has also been increasing.

Gas turbines. Originally developed for jet engines, gas turbines are now widely used in the power industry. Small industrial gas turbines of 1–20 MW are commonly used in combined heat and power applications. They are particularly useful when higher temperature steam is required than can be produced by a reciprocating engine. The maintenance cost is slightly lower than for reciprocating engines, but so is the electrical conversion efficiency. Gas turbines can be noisy. Emissions are somewhat lower than for engines, and cost-effective NO_x emission control technology is commercially available.

Micro turbines. Micro turbines extend gas turbine technology to units of small size. The technology was originally developed for transportation applications, but is now finding a place in power generation. One of the most striking technical characteristics of micro turbines is their extremely high rotational speed. The turbine rotates up to 120 000 r/min and the generator up to 40 000 r/min. Individual units range from 30 to 200 kW but can be combined into systems of multiple units. Low combustion temperatures can assure very low NO_x emission levels. These turbines make much less noise than an engine of comparable size. Natural gas is expected to be the most common fuel but flare gas, landfill gas or biogas can also be used. The main disadvantages of micro turbines are their short track record and high costs compared with gas engines.

Fuel cells. Fuel cells are compact, quiet power generators that use hydrogen and oxygen to make electricity. The transportation sector is the major potential market for fuel cells, and car manufacturers are making substantial investments in research and development. Power generation, however, is seen as a market in which fuel cells could be commercialized much more quickly. Fuel cells can convert fuels to electricity at very high efficiencies (35–60 %), compared with conventional technologies [8]. As there is no combustion, other noxious emissions are low. Fuel cells can operate with very high reliability and so could supplement or replace grid-based electricity. Only one fuel cell technology for power plants, a phosphoric acid fuel cell plant (PAFC), is currently commercially available. Three other types of fuel cells, namely molten carbonate (MCFC), proton exchange membrane (PEMFC) and solid oxide (SOFC), are the focus of intensive research and development.

Photovoltaic systems. Photovoltaic systems are a capital-intensive, renewable technology with very low operating costs. They generate no heat and are inherently small scale. These characteristics suggest that photovoltaic systems are best suited to household or small commercial applications, where power prices on the grid are highest. Operating costs are very low, as there are no fuelling costs.

Wind. Wind generation is rapidly gaining a share in electricity supply worldwide. Wind power is sometimes considered to be DG, because the size and location of some wind farms make it suitable for connection at distribution voltages.

1.3.2 Thermal Issues

When DG is connected to the distribution network, it alters the load pattern. The amount of feeder load demand will eventually result in the feeder becoming fully loaded. It is most likely that increased levels of DG will cause an increase in the overall current flowing in the network, bringing the components in the network closer to their thermal limits. If the thermal limits of the circuit components are likely to be exceeded by the connection of DG, then the potentially affected circuits would need to be replaced with circuits of a higher thermal rating. This would usually take the form of replacement with conductors of a larger cross-sectional area.

1.3.3 Voltage Profile Issues

Voltage profiles along a loaded distribution network feeder are typically such that the voltage level is at maximum close to the distribution network transformer busbar, and the voltage drops along the length of the feeder as a result of the load connected to the feeder. Voltage drop is generally larger on rural networks, which are commonly radial networks with feeders covering long distances with relatively low-current-capacity conductors, especially at the remote ends of the feeders. The distribution transformer, feeding the distribution network, is fitted with a tap-changer, which controls the setting of the busbar voltage. The tap-changer will be set to ensure that, under maximum feeder loads, the voltage drop along a feeder does not result in voltage levels falling below the lower of the statutory voltage limits.

DG along a distribution feeder will usually have the effect of reducing the voltage drop along the feeder, and may lead to a voltage rise at some points which could push the feeder voltage above the statutory voltage limit. Voltage rise is generally more of a problem on rural radial networks than on interconnected or ring networks, as excessive voltage rise can be initiated by relatively small amounts of DG due to the high impedance of the conductors and because these feeders are often operated close to the statutory upper voltage limit to counter the relatively large voltage drop over the length of such feeders. Voltage rise may be reduced by:

1. Constraining the size of DG plant: the level of voltage rise will depend upon the generation level compared with the minimum load demand.
2. Reinforcing the network (initially using larger conductors with a lower impedance).
3. Operating the generator at a leading power factor (i.e. importing VArs from the network), which will reduce overall power flow and hence reduce voltage drop. However, distribution network operators (DNOs) generally require DG plant to operate as close to unity power factor as possible (i.e. negligible import or export of reactive power).
4. Installing shunt reactor banks to draw additional reactive power from the network. DG could also contribute to voltage flicker through sudden variations in the DG output (e.g. variable wind speeds on turbines), start-up of large DG units or interactions between DG and voltage control equipment on the network. Wind turbines with induction generators will cause voltage disturbances when starting, due to the inrush of reactive current required to energize the rotor. The voltage step that will occur when a wind turbine shuts down from full output, perhaps due to high wind speeds, must also be considered. A short-term reduction in the network voltage means that there is not enough energy to supply the connected load. There are two major causes of these voltage dips: namely, sudden connections of large loads or faults on adjacent branches of the network. When DG is connected to a network and is energized, a voltage step may result from the inrush current flowing into the generator or transformer. Step voltages also occur when a generator (or group of generators) is suddenly disconnected from the network, most likely due to a fault.

When large motor loads are suddenly connected to the network, they draw a current, which can be many times larger than the nominal operating current. The supply conductors for the load are designed for nominal operation; therefore this high current can cause an excessive voltage drop in the supply network. Voltage dips caused by large motor loads can be overcome by installing a starter, which limits the starting current but increases the starting time. Another option is to negotiate with the DNO for a low-impedance connection, though this could be an expensive option depending on the local network configuration. Depending on the reaction time of control systems, there are several options to reduce the severity of voltage dips: that is, to increase DG output, to reduce network loads, to utilize energy from storage devices or energize capacitor banks.

1.3.4 Fault-Level Contributions

A fault can occur in many ways on a network due to a downed overhead line or a damaged underground cable. The current that flows into a fault can come from three sources on a distribution network: namely, infeeds from the transmission system, infeeds from distributed generators or infeeds from loads (with induction motors).

The connection of DG causes fault levels close to the point of connection to increase. This increase is caused by an additional fault level from the generator, and can cause the overall fault level to exceed the designed fault level of the distribution equipment. Increased fault levels can be accommodated, or reduced, by either upgrading equipment or reconfiguring distribution networks.

Induction generators contribute very little to root mean square (RMS) break fault levels, as the fault current from the induction generator quickly collapses as the generator loses magnetic excitation due to the loss of grid supply. However, they contribute more to peak fault levels. Synchronous generators contribute less to the initial peak current compared with induction generators but do have a larger steady-state RMS fault contribution. For generators which are connected to the distribution network via power electronics interfaces, it will be quickly disconnected under network fault conditions when a current is 20 % higher than the rated current. As a doubly fed induction generator (DFIG) is only partially connected via power electronics, the RMS break fault current contribution is low. However, the peak current contribution can be up to six times the rated current.

1.3.5 Harmonics and Interactions with Loads

In ideal electricity network the voltage would have a perfectly sinusoidal waveform oscillating, for example, at 50 cycles per second. However, any capacitive or inductive effects, due to switching of devices such as large cables, network reactors, rectified DC power supplies, variable speed motor drives and inverter-coupled generators, will introduce or amplify ‘harmonic’ components into the voltage sine wave, thereby distorting the voltage waveform. It is expected that small-scale micro wind and solar generation will be inverter connected. Inverter connections incorporate the use of a high proportion of switching components that have the potential to increase harmonic contributions.

1.3.6 Interactions Between Generating Units

Increasing levels of intermittent renewable generation and fluctuating inputs from CHP units will ultimately make it more difficult to manage the balance between supply and demand of the power system. Unless the DG can offer the same control functions as the large generators on the system, the amount of generation reserve required when there is a significant contribution to the system from DG will need to be increased.

1.3.7 Protection Issues

Distribution networks were designed to conduct current from high to low voltages and protection devices are designed to reflect this concept. Under conditions of current flow in the opposite direction, protection mal-operation or failure may occur with consequent increased risk of widespread failure of supply.

Due to opposite current flow, the reach of a relay is shortened, leaving high-impedance faults undetected. When a utility breaker is opened, a portion of the utility system remains energized while isolated from the remainder of the utility system, resulting in injuries to the public and utility personnel. Figure 1.2 shows an islanding situation where IM, SM and CB stand for induction machine, synchronous machine and circuit breaker, respectively [9].

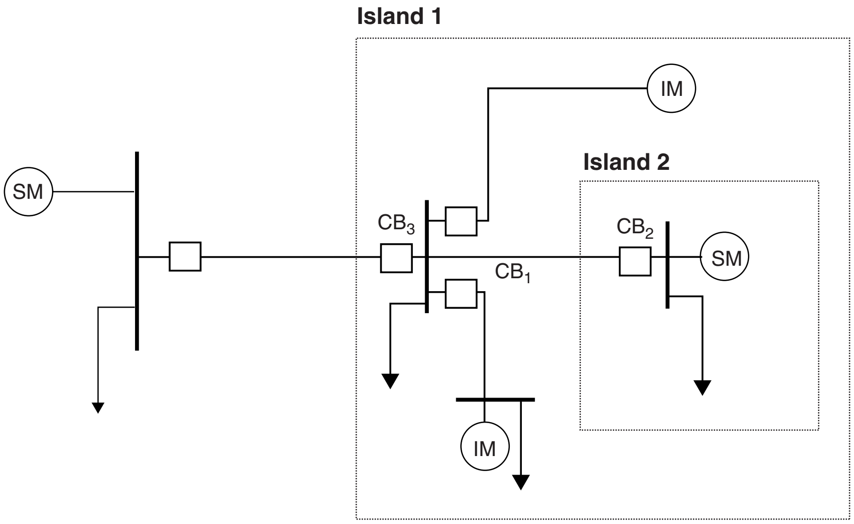

Figure 1.2 *Islanding operation. Reproduced by permission of T.-F. Chan and L. L. Lai, 'Permanent-Magnet Machines for Distributed Power Generation: A Review' paper No. 07GM0593, IEEE 2007 General Meeting, Tampa, USA. Copyright ©(2007) IEEE + reference to publication, author*

1.4 Economic Impact of DG

DG has some economic advantages compared with power from the grid, particularly for on-site power production [10–12]. The possibility of generating and using both heat and power generated in a CHP plant can create additional economic opportunities. DG may also be better positioned to use low-cost fuels such as landfill gas.

The relative prices of retail electricity and fuel costs are critical to the competitiveness of any DG option. This ratio varies greatly from country to country. In Japan, for example, where electricity and natural gas prices are high, DG is attractive only for oil-fired generation. In other countries, where gas is inexpensive compared with electricity, DG can become economically attractive. Many DG technologies can be very flexible in their operation. A DG plant can operate during periods of high electricity prices (peak periods) and then be switched off during low-price periods.

The ease of installation of DG also allows the system capacity to be expanded readily to take advantage of anticipated high prices. Some DG assets are portable. In addition to this technological flexibility, DG may add value to some power systems by delaying the need to upgrade a congested transmission or distribution network, by reducing distribution losses and by providing support or ancillary services to the local distribution network.

CHP is economically attractive for DG because of its higher fuel efficiency and low incremental capital costs for heat-recovery equipment. Domestic-level CHP, so-called ‘micro-CHP’, is attracting much interest, particularly where it uses external combustion engines and in some cases fuel cells. However, despite the potential for short payback periods, high capital costs for the domestic consumer are a significant barrier to the penetration of these technologies.

The provision of reliable power represents the most important market for DG. Emergency diesel generating capacity in buildings, generally not built to export power to the grid, represents several per cent of total peak demand for electricity. Growing consumer demand for higher quality electricity (e.g. ‘five nines’ or 99.999 % reliability) requires on-site power production.

Many of these technologies can be more energy efficient and cleaner than central station power plants. Modularity is beneficial when load growth is slow or uncertain.

The smaller size of these technologies can better match gradual increases in utility loads. DG also can reduce demand during peak hours, when power costs are highest and the grid is most congested. If located in constrained areas, DG can reduce the need for distribution and transmission system upgrades. Customers can install DG to cap their electricity costs, sell power, participate in demand response programmes, provide backup power for critical loads and supply premium power to sensitive loads.

The biggest potential market for DG is to supplement power supplied through the transmission and distribution grid. On-site power production reduces transmission and distribution costs for the delivery of electricity. These costs average about 30 % of the total cost of electricity. This share, however, varies according to customer size. For very large customers taking power directly at transmission voltage, the total cost and percentage are much smaller; for a small household consumer, network charges may constitute over 40 % of the price.

Small-scale generation has a few direct cost disadvantages over central generation. First, there is a more limited selection of fuels and technologies to generate electricity – oil, natural gas, wind or photovoltaic systems, and, in certain cases, biomass or waste fuels. Second, the smaller generators used in DG cost more per kilowatt to build than larger plants used in central generation. Third, the costs of fuel delivery are normally higher. Finally, unless run in CHP mode, the smaller plants used in DG operate usually at lower fuel conversion efficiencies than those of larger plants of the same type used in central generation. DG uses a more limited selection of fuels. For photovoltaic systems, operating costs are very low, but high capital costs prevent them from competitive with grid electricity.

1.5 Barriers to DG Development

Cooperation, property ownership, personal consumption and security will change attitudes towards DG technologies and make people welcome them to their homes. There is now evidence of strong interest from a small community willing to pay the premium to enjoy green energy [13].

There is significant regional variation in the use of DG systems. This is largely due to the fact that the potential benefits of DG are greater in some areas than others. In some areas, for example, relatively high electricity rates, reliability concerns and DG-friendly regulatory programmes have encouraged comparatively fast DG development. But in many areas, even where DG could offer benefits, projects are often blocked by market and other barriers. The most commonly cited barrier to DG development is the process of interconnecting to distribution and transmission systems. Other barriers include high capital costs, non-uniform regulatory requirements, lack of experience with DG, and tariff structures [14–16].

The lack of experience with competitive markets often increases risk about the use of unconventional power sources. Customers cannot easily sell power from on-site generation to the utility through a competitive bidding process, to a marketer or to other customers directly. For customers, there is a risk of DG being uneconomical; capital investments under market uncertainty; price volatility for the DG system fuel. There is a concern about the reliability and risks that arise from using unconventional technologies/applications with DG.

Utilities have a considerable economic disincentive to embrace distributed resources. Distribution company profits are directly linked to sales. Utilities' revenues are based on how much power they sell and move over their wires, and they lose sales when customers develop generation on site. Interconnecting with customer-owned DG is not in line with a utility's profit motive. Other barriers to the deployment of DG exist on the customer side. A utility has no obligation to connect DG to its system unless the unit is a qualifying facility. If a utility does choose to interconnect, lengthy case-by-case impact studies and redundant safety equipment can easily spoil the economics of DG. If a customer wants the utility to supply only a portion of the customer's load or provide backup power in case of unit failure, the cost of 'standby' and 'backup' rates can be prohibitive. Exit fees and competitive transition charges associated with switching providers or leaving the grid entirely can be burdensome. And obtaining all the necessary permits can be quite difficult.

1.6 Renewable Sources of Energy

These are the natural energy resources that are inexhaustible: for example, wind, solar, geothermal, biomass and small-hydro generation.

Small-hydro energy. Although the potential for small hydroelectric systems depends on the availability of suitable water flow, where the resource exists it can provide cheap, clean, reliable electricity. Hydroelectric plants convert the kinetic energy of a waterfall into electric energy. The power available in a flow of water depends on the vertical distance the water falls and the volume of the flow of water. The water powers a turbine, and its rotation movement is transferred through a shaft to an electric generator. A hydroelectric installation alters its natural surroundings. The effects on the environment must therefore be evaluated during the planning of the project to avoid problems such as noise or damage to ecosystems.

Wind energy. Wind turbines produce electricity for homes, businesses and utilities. Wind power will continue to prosper as new turbine designs currently under development reduce its costs and make wind turbines economically viable in more and more places. Wind speed varies naturally with the time of day, the season and the height of the turbine above the ground. The energy available from wind is proportional to the cube of its speed. A wind generator is used to convert the power of wind into electricity. Wind generators can be divided into two categories, those with a horizontal axis and those with a vertical axis [17]. The Electric Power Research Institute, USA, has stated that wind power offers utilities pollution-free electricity that is nearly cost-competitive with today's conventional sources. However, one environmental concern about wind power is land use. Modern wind turbine technology has made significant advances over the last 10 years. Today, small wind machines of 5 to 40 kW capacity can supply the normal electrical needs of homes and small industries. Medium-size turbines rated from 100 to 500 kW produce most of the commercially generated electricity.

Biomass. The term biomass refers to the Earth's vegetation and many products that come from it. Some of the commonest biomass fuels are wood, agricultural residues and crops grown for energy. Utilities and commercial and industrial facilities use biomass to produce electricity. According to the World Bank, 50 to 60 % of the energy in the developing countries of Asia, and 70 to 90 % of the energy in the developing countries of Africa, come from biomass, and half the world's population cook with wood. In the USA, Japan and Europe, municipal and agricultural waste are being burned to produce electricity.

Solar energy. Solar thermal electric power plants use various concentrating devices to focus sunlight and achieve the high temperatures necessary to produce steam for power. Flat-plate collectors transfer the heat of the Sun to water either directly or through the use of another fluid and a heat exchanger. The market for photovoltaics is rapidly expanding. Homes can use photovoltaic systems to replace or supplement electric power from the utility. A stand-alone residential system consists of solar panels, a battery to store power for use at night, and an inverter to allow conventional appliances to be powered by solar electricity.

Geothermal. Geothermal energy is heat from the Earth that is used directly as hot water or steam, or used to produce electricity. While high-temperature geothermal sites suitable for electricity production are not widespread, low-temperature sites are found almost everywhere in the world and they can provide heating and cooling for buildings. Geothermal systems are located in areas where the Earth's crust is relatively thin. Drilling into the ground and inserting pipes enable hot water or steam to be brought to the surface. In some applications, this is used to provide direct heating to homes. In other areas, the steam is used to drive a turbine to generate electricity. According to the US Energy Information Agency, geothermal energy has the potential to provide the USA with 12 000 megawatts of electricity by the year 2010, and 49 000 megawatts by 2030. It has the potential to provide up to 80 000 megawatts. Geothermal energy resources are found around the world. As a local and renewable energy resource, geothermal energy can help reduce a nation's dependence on oil and other imported fuels. Geothermal heat pumps (GHPs) are an efficient way to heat and cool buildings. GHPs use the normal temperature of the Earth to heat buildings in winter and cool them in summer. GHPs take advantage of the fact that the temperature of the ground does not vary as much from season to season as the temperature of the air.

1.7 Renewable Energy Economics

Generating electricity from the wind makes economic as well as environmental sense: wind is a free, clean and renewable resource which will never run out. The wind energy industry – designing and making turbines, erecting and running them – is growing fast and is set to expand as the world looks for cleaner and more sustainable ways to generate electricity. Wind turbines are becoming cheaper and more powerful, with larger blade lengths which can utilise more wind and therefore produce more electricity, bringing down the cost of renewable generation.

Making and selling electricity from the wind is no different from any other business. To be economically viable the cost of making electricity has to be less than its selling price. In every country the price of electricity depends not only on the cost of generating it, but also on the many different factors that affect the market, such as energy subsidies and taxes. The cost of generating electricity comprises capital costs (the cost of building the power plant and connecting it to the grid), running costs (such as buying fuel and operation and maintenance) and the cost of financing (how the capital cost is repaid).

With wind energy, and many other renewables, the fuel is free. Therefore once the project has been paid for, the only costs are operation and maintenance and fixed costs, such as land rental. The capital cost is high, between 70 and 90 % of the total for onshore projects. The more electricity the turbines produce, the lower the cost of the electricity. This depends on the power available from the wind. Roughly, the power derived is a function of the cube of the wind speed. Therefore if the wind speed is doubled, its energy content will increase eight fold. Turbines in wind farms must be arranged so that they do not shadow each other.

The cost of electricity generated from the wind, and therefore its final price, is influenced by two main factors, namely technical factors and financial perspective. Technical factors are about wind speed and the nature of the turbines, while financial perspective is related to the rate of return on the capital, and the period of time over which the capital is repaid. Naturally, how quickly investors want their loans repaid and what rate of return they require can affect the feasibility of a wind project; a short repayment period and a high rate of return push up the price of electricity generated. Public authorities and energy planners require the capital to be paid off over the technical lifetime of the wind turbine, e.g. 20 years, whereas the private investor would have to recover the cost of the turbines during the length of the bank loan. The interest rates used by public authorities and energy planners would typically be lower than those used by private investors.

Although the cost varies from country to country, the trend is everywhere the same: that is, wind energy is getting cheaper. The cost is coming down for various reasons. The turbines themselves are getting cheaper as technology improves and the components can be made more economically. The productivity of these newer designs is also better, so more electricity is produced from more cost-effective turbines. The cost of financing is also falling as lenders gain confidence in the technology. Wind power should become even more competitive as the cost of using conventional energy technologies rises.

The economics of wind energy are already strong, despite the young age of the industry. The world market in wind turbines continues to boom: a comprehensive policy package combining the best elements of market-based incentives and technology policy approaches will accelerate the implementation of existing clean, energy-efficient technologies; stimulate the development of renewable domestic energy sources; and promote research and development on efficient new technologies. Investment in efficient, clean energy technologies lowers business costs and boosts the productivity and competitiveness of industry. That means faster economic growth, more jobs and higher wages. An emission trading scheme will encourage innovation and stimulate investment in the lowest cost techniques to reduce GHGs. Low-emission plants are used to offset higher emissions made by others, with the aim that the utility in total meets emission requirements. The Clean Development Mechanism (CDM) is an arrangement under the Kyoto Protocol allowing developed countries with a GHG reduction commitment to invest in emission-reducing projects in developing countries as an alternative to what is generally considered more costly emission reductions in their own countries [18]. This mechanism will also help promote renewable generation. Figure 1.3 shows the price trend of EU emissions trading in 2005.

However, renewable energy technologies will introduce new conflicts. For example, a basic parameter controlling renewable energy supplies is the availability of land. At present world food supply mainly comes from land. There is relatively little land available for other uses, such as biomass production and solar technologies. Population growth demands land. Therefore, future land conflicts will be intensified. Although renewable energy technologies often cause fewer

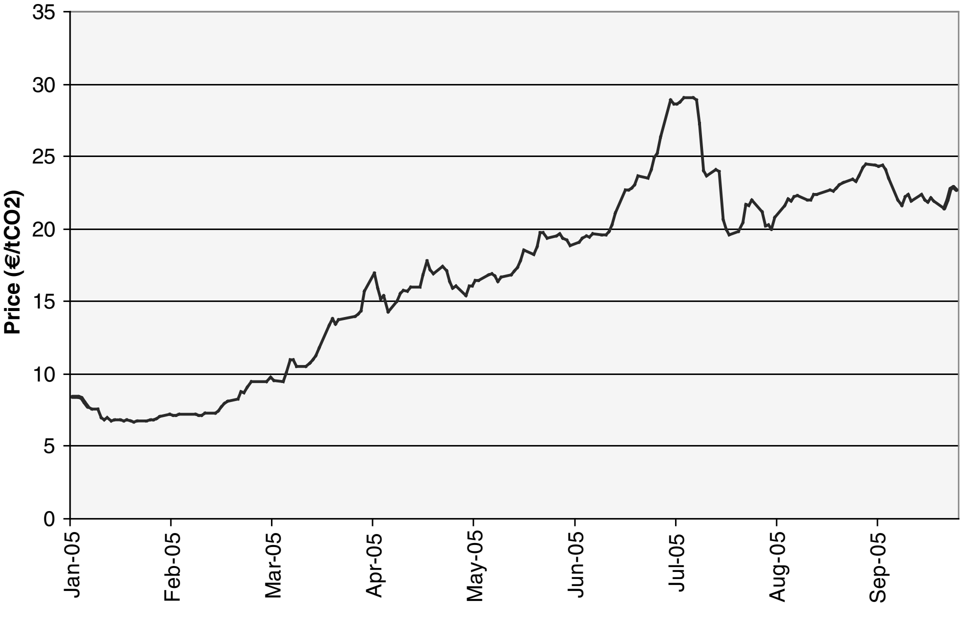

Figure 1.3 *The EU emissions trading scheme. Reproduced by permission of T.-F. Chan and L. L. Lai, 'Permanent-Magnet Machines for Distributed Power Generation: A Review' paper No. 07GM0593, IEEE 2007 General Meeting, Tampa, USA. Copyright ©(2007) IEEE + reference to publication, author*

environmental problems than fossil energy systems, they require large amounts of land and therefore compete with agriculture, forestry and other essential land-use systems. Reservoirs constructed for hydroelectric plants have the potential to cause major environmental problems. This water cover represents a major loss of productive agricultural land. Dams may fail, resulting in loss of life and destruction of property. Further, dams alter the existing plant and animal species in an ecosystem, e.g. by blocking fish migration. Generation, transmission and distribution utilities generally plan their systems to meet all of the power needs of all of their customers. They do not encourage their customers to develop on-site generation. In some cases, utilities have actively opposed DG projects.

1.8 Interconnection

1.8.1 Interconnection Standardization

A customer who wants to interconnect DG to the distribution system must undergo a utility's case-by-case interconnection review process [19–24]. Such a process can be time consuming and expensive. Installers thus face higher costs by having to meet interconnection requirements that vary from utility to utility. Additionally, manufacturers are not able to capture the economies of scale in producing package systems with standard safety and power quality protection. The interconnection process would benefit from the pre-certification of specific DG technologies. Recognized, independent or government testing labs (e.g. Underwriters Laboratories) would conduct initial testing and characterization of the safety, power quality and system reliability impacts of DG. They would recommend technical parameters that state legislatures, regulatory agencies or individual utilities could adopt.

1.8.2 Rate Design

The restructuring of electricity markets and an increased reliance on wholesale power purchases have brought distribution into the spotlight. As utilities have divested themselves of generation assets, they have become aware of the importance of distribution services in generating revenue. Usage-based rates help ensure that customers pay the actual costs they impose on the system so that their consumption neither subsidizes nor is subsidized by the consumption of others.

Rates should reflect the grid benefits of DG, like peak shaving, reduced need for system upgrades, capital cost reductions and increased reliability. Standby or backup charges are rates that a customer pays to receive power from the grid at times when its own DG is unavailable. Standby rates are typically based on serving a customer's maximum load at peak demand periods – a worst case scenario which, some argue, should not serve as the basis for rate making. Buyback rates are the prices a utility pays for excess generation from a customer's own DG unit. Buyback rates or credits would be higher for energy derived from DG located in constrained areas of the distribution system. Finally, DG owners sometimes face the implications of 'stranded costs' of utility investments in restructured markets. Competitive transition charges and exit fees can apply when a DG customer–owner seeks to switch providers or disconnect from the grid entirely.

In the future, one key area of concern is the technical details of interconnecting DG with the electric power systems (EPSs). RES will contribute to meet the targets of the Kyoto Protocol and support the security of supply with respect to limited energy resources. The interconnection must allow DG sources to be connected with the EPS in a manner that provides value to the end user without compromising reliability or performance.

The situation in Europe differs from country to country. Circumstances may also differ between synchronous interconnected systems and island systems. The capacity targets and the future portfolio of RES depend on the national situation. Nevertheless the biggest growth potential is for wind energy. The expectations of the European Wind Energy Association show an increase from 28.5 GW in 2003 to 180 GW in 2020. Due to different support schemes for RES restrictions in licensing and a limited number of suitable locations, this capacity tends to focus on very few regions in Europe. However, new wind farms will normally be built far away from the main load centres. New overhead lines will therefore be necessary to transport the electricity to where it is consumed. These investments are exclusively or at least mainly driven by the new RES generation sites. The intermittent contributions from wind power must be balanced with other backup generation capacity located elsewhere. This adds to the requirements for grid reinforcements.

The licensing procedures for new lines are lasting several years, some even more than 10 years. A delay in grid extension will result in a delay of RES investments because wind farms cannot earn an adequate return on investment without an adequate grid connection. New lines are therefore critical for the success of new RES. Moreover, this new infrastructure could be a significant investment. There is not yet a European-wide harmonized rule about who should pay for it. The legal framework and administrative procedures have to be set properly to speed up the licensing of grid infrastructure.

As countermeasures, suitable European-wide harmonized grid codes for new wind farms and other RES defining their electrical behaviour in critical grid situations are needed in all countries expanding their share of RES. Existing wind farms not fulfilling the actual grid code requirements must be upgraded or replaced (i.e. the electrical behaviour of wind turbines in case of grid faults). Finally, a sufficient capacity from conventional generation has to be in the system at any one time to keep it stable.

1.9 Recommendations and Guidelines for DG Planning

Liberalization and economic efficiency. Liberalization of the electricity market has increased the complexity and transaction costs for all market players and particularly affected smaller producers. In certain markets where they can avoid charges on transmission, distributed generators may have an advantage over central generators. Elsewhere, in wholesale markets that are designed with large central generation in mind, smaller distributed generators may be at a disadvantage because of the additional costs and complexities of dealing with the market. Difficulties in the New Electricity Trading Arrangements (NETA)/British Electricity Trading and Transmission Arrangements (BETTA) market in the UK suggest that further market measures are needed to make the system fair to smaller generators [25]. Furthermore, treatment of connection charges for DG needs to be consistent with treatment of larger generators. In fact, liberalization of the electricity market is not broad enough to take advantage of the flexibility of many types of DG. Retail pricing should encourage the development of DG in locations where it can reduce network congestion and operate at times when system prices are high.

Environmental protection. DG embraces a wide range of technologies with a wide range of both NO_x and GHG emissions. Emissions per kWh of NO_x from DG (excepting diesel generators) tend to be lower than emissions from a coal-fired power plant. At the same time, the emissions rate from existing DG (excepting fuel cells and photovoltaics) tends to be higher than the best available central generation, such as a combined cycle gas turbine with advanced emissions control. This puts a serious limitation on DG in areas where NO_x emissions are rigorously controlled. If, however, DG is used in a CHP mode, there can be significant emissions savings, even compared with combined cycle power plants. Measures should be designed that encourage distributed generators to reduce their emissions. The use of economic instruments (such as carbon emissions trading) would encourage DG operators to design and operate their facilities in ways that minimize emissions of GHGs.

Regulatory issues and interest in DG. The profits of distribution companies are directly linked to sales. The more kilowatt hours of electricity that move over their lines, the more money they make. Interconnecting with customer-owned DG is plainly not in line with a utility's profit motive. Permission to connect to the grid should be restricted only for safety and grid protection. Guidelines should ensure that there are no restrictions, other than for safety or grid protection reasons.

The following issues need to be addressed [26–31]:

- Adopt uniform technical standards for connecting DG to the grid.
- Adopt testing and certification procedures for interconnection equipment.
- Accelerate development of control technology and systems. While policy increases interest in DG, regulatory and institutional barriers surrounding the effective deployment of DG remain.
- Adopt standard commercial practices for any required utility review of interconnection.
- Establish standard business terms for interconnection agreements.

- Develop tools for utilities to assess the value and impact of distributed power at any point on the grid.
- Develop new regulatory principles compatible with the distributed power choices in competitive and utility markets.
- Adopt regulatory tariffs and utility incentives to fit the new distributed power model. Design tariffs and rates to provide better price transparency to DG.
- Define the condition necessary for a right to interconnect.
- Develop a well-designed policy framework that will reward efficiency and environmental benefits in DG technologies the same way as it does for conventional large-scale generators.
- Include critical strategies for consumer education and cost evaluation tools to deploy DG effectively.
- Design rate for standby charges, interconnection fees, exit fees and grid management charges.

Distributed generators must be allowed to connect to the utility grid. The owners of DG must recognize the legitimate safety and reliability concerns associated with interconnection. Regulators must recognize that the requirements for utility studies and additional isolation equipment will be minimal in the case of smaller DG units.

1.10 Summary

DG has the potential to play a major role as a complement or alternative to the electric power grid under certain conditions. DG is fundamentally distinct from the traditional central plant model for power generation and delivery in that it can deliver energy close to loads within the power distribution network. Three relatively independent sources of pressure, namely restructuring, the need for new capacity and DG technology advancements, are collectively laying the groundwork for the possible widespread introduction of DG. Standards for control/communications should be developed to enable DG better to participate in markets.

But DG is not necessarily a benefit for all players in the electricity sector. Utilities may see customers with on-site generation as problematic because they have different consumption patterns than the average customers. DG usually requires the site to have the same service capacity from the utility as that before installation while the customer is buying less energy, i.e. the load factor on installed utility capacity is reduced.

Depending on the operating scheme and relative performance of the DG system and the power plants supplying the grid, fuel consumption, carbon and other pollutant emissions, and noise pollution can all increase or decrease with DG adoption. For these reasons, DG policy needs to encourage applications that benefit the public, while discouraging those from which the public incurs a net cost. Inherent in this, there is a need to analyse DG costs and benefits and the influence of public policy on DG adoption and operation. While DG may itself become a dominant force in the provision of energy, it is its capability to be used in numerous locations and become integrated into the grid that gives it its greatest value.

Public confidence and interest in DG technologies will depend on the availability of reliable technical support. For example, micro-CHP units and solar water heaters require adjustments to a hot water system at home to deliver carbon savings. DG will only have a chance of success if licensing, regulation and pricing regimes can be made so that users of DG technologies are allowed to benefit equitably. Ultimately, there has to be a clear, consistent and long-term market framework. One can envisage the emergence of networks consisting of a large number of local networks with self-sufficiency (islanding) capabilities, connected by a national grid. Recent technological advances in communications, energy storage and automation can make this possible.

Recent developments in the regulatory arrangements and incentives to connect, particularly renewable technologies, to transmission and distribution networks have meant that the traditional pattern of network usage has altered and this situation is likely to continue. One of the principal changes has been the increase in the volume of DG connected to the network. In certain circumstances, this makes use of the transmission network without being liable for transmission charges, and yet its impact on network flows may lead to additional transmission investment.

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