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UK ELECTRICITY NETWORKS

The Government wishes to increase the contribution of renewable electricity and Combined Heat and Power (CHP)[1] to UK energy supplies. Much of this technology will be small-scale and situated close to where its output is used. The electricity output may be less predictable than from sources such as gas, coal-fired or nuclear power stations. The configuration, operation and regulation of current national electricity networks may therefore need modification. This briefing explores the regulatory, economic and technical implications arising. It accompanies a related but separate briefing on renewable energy (POSTnote 164).

The current situation

The first electricity networks developed around 120 years ago as localised street systems and have evolved to become today's interconnected national transmission and distribution network. **Transmission** is the bulk, often long distance, movement of electricity at high voltages (400kV [400,000 volts] - and 275kV) from generating stations to distribution companies and to a small number of large industrial customers. **Distribution** is electricity provision to the majority of customers through lower voltage, more localised networks (from 132kV to 230V).

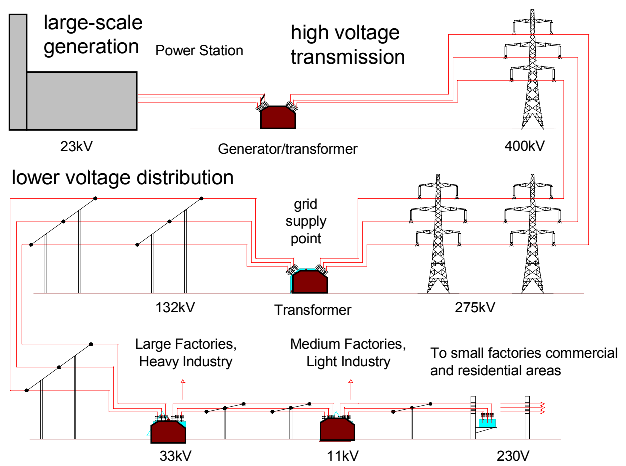
The UK electricity supply industry (ESI) has a structure (figure opposite) characterised by:

- large-scale generation plants
- high voltage networks
- integrated generation, transmission, distribution and supply functions.

Transmission

There are four transmission systems in the UK - one in England and Wales, two in Scotland, and one in Northern Ireland. Each is separately operated and owned. The largest, in terms of line length and share of total transmission is the National Grid Company (NGC) system, covering England and Wales (see box opposite).

An interconnected electricity system



> **The National Grid Company plc**
>
> The high voltage (400kV and 275kV) transmission system, through which bulk electricity is moved, is owned and operated by the National Grid Company plc (NGC). NGC's holding company (The National Grid Group plc) was floated on the stock market in 1995. NGC's statutory duties (regulated by the Office of Gas and Electricity Markets, Ofgem) include:
>
> - the development and maintenance of an efficient, co-ordinated and economic transmission system
> - facilitation of competition in electricity supply and generation
> - preservation of amenity (e.g. ensuring that the landscape is not adversely affected by overhead power lines and support towers – commonly known as pylons)
> - care for the environment (e.g. avoiding pollution)
>
> NGC also has a duty to provide transparent information on charges for the use of the network and its capability and characteristics, including opportunities for future use and guidance to anyone who wishes to connect.

NGC also operates electricity 'interconnectors' – overhead lines connecting the transmission networks in England

and Wales to Scotland, and an undersea link that connects France and England[2]. Transmission operators also have a role in balancing generation and demand at all times, to secure the security of the network. They do this through electricity trading[3], and by purchasing **ancillary services** (see box below).

Ancillary services

These are services provided to ensure the security and stability of the whole electricity network. They include:

- Voltage and frequency response. Electricity is supplied at a given voltage and frequency (e.g. for domestic supplies it is supplied at a voltage of 230V and a frequency of 50 cycles per second (hertz, Hz). The exact voltage and frequency of electricity on the network any one time varies as the demand and supply fluctuate. Ancillary services therefore include monitoring and responding to these variations to ensure the 'quality' of supply in terms of maintaining voltage and frequency within acceptable limits.
- Providing spare capacity to respond to the failure of generation plant and inaccuracy in demand forecasts.
- Ensuring the availability of generating units capable of producing electricity in the event of a catastrophic failure of the network and complete power loss.

In England and Wales, NGC purchases these services from generators and some consumers. For instance, if there is a danger that overall demand might exceed supply, NGC could pay a firm to reduce its own demand. For example, at half time in an international football match TV viewers might go to make a cup of tea, requiring an increase in electricity supply as water is boiled in millions of kettles. If the supply cannot be met by extra generation alone, NGC may ask a factory with a large demand (e.g. an electroplating works) to shut down for a short time to enable the supply to domestic customers to be maintained.

Distribution

There are 12 licensed Distribution Network Operators (DNOs) in England and Wales, two in Scotland and one in Northern Ireland. They include GPU Power UK, Norweb and SEEBOARD Power Networks, and their size and number of customers varies. DNOs hold regional licences for the provision of distribution network services and are regulated by the Office of Gas and Electricity Markets (Ofgem). DNOs are under a statutory duty to connect any customer requiring electricity within a defined area, and to maintain that connection[4].

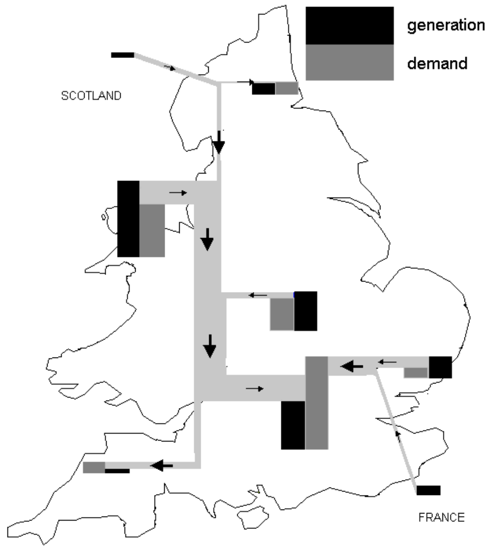
Benefits of an interconnected system

Until the 1930s, separate private and municipally owned utilities provided electricity in the UK. The Electricity (Supply) Act 1926 sought to minimise the wasteful duplication of resources, e.g. each authority installing enough generating plant to cover equipment breakdown and maintenance, by creating an interconnected network (the 'grid').

Through this, bulk electricity could flow across the high voltage network, now allowing the geographic mismatch between generation (mostly in the North and Midlands) and demand (highest in the South) to be reconciled - see figure opposite. The box opposite outlines other key benefits of interconnection.

Electricity Flow Pattern – 2001/2002

Source: National Grid Company plc



Benefits of interconnection

Economic operation

Connecting all electricity generators through the transmission system allows use of the cheapest generation available, no matter where it is.

Customer security of supply

Providing the customer with a continuous and uninterrupted electricity supply of the required quantity and of defined quality (see box on ancillary services) requires electricity networks to continue to provide electricity even if certain generators, or parts of the transmission or distribution networks fail. Interconnected networks allow exploitation of the capacity and location of individual generation sources and demand to maintain security of supply.

Spare generation capacity

Additional generating capacity is needed to cover for understated demand forecasts and for generating plant being unavailable due to plant breakdown, routine shutdowns, delay in commissioning of new units or adverse weather. Surplus generation capacity in one area can cover shortfalls elsewhere, reducing the need for spare capacity across the whole network.

Reduction in frequency response

System frequency varies continuously and depends on a careful balance between demand and generation. Interconnection allows the frequency of the system to be controlled without each separate system having to maintain its own frequency.

Drivers for change

Since the late 1980s, there have been significant changes within the ESI, such as the liberalisation of electricity markets, technological advances, tighter financial/lending constraints and increased environmental concerns (see box on next page).

Each of these, to some extent, has fuelled interest in low-capital, small scale, fast revenue generating projects, such as modern gas-fired power stations (combined cycle gas turbines, CCGTs), wind turbines and CHP plant.

Policy and technology drivers in the ESI

Economic drivers
- Deregulation and competition policy aimed at ensuring the lowest possible costs for all consumers through a system of price controls
- Diversification of energy and fuel sources
- The shorter construction times, lower capital costs and quicker payback periods of smaller units
- Location of generating plant nearer to demand, thus reducing transmission charges.

Technological drivers
- Improved technological performance of small-scale generating plant and control technologies.

Environmental drivers
- Reduction in environmental impact of electricity generation (including acid gases, waste management and carbon dioxide, CO_2)
- Energy efficiency (although this is also an economic and technological driver)
- Increased difficulty – planning, public concerns, etc. – in locating large generating units.

The Government has set targets for increasing renewable energy and CHP[5]. It also wants the UK to be at the forefront of the liberalisation of electricity markets and the promotion of advanced technologies to enhance competitiveness and provide greater opportunities for the growth of overseas markets for energy technologies and services.

The Utilities Act 2000, recognising recent structural changes within energy markets, amends the structure and regulatory framework of the ESI. It places statutory duties on DNOs similar to those on the NGC, requiring them to facilitate competition in generation and supply, to develop and maintain an efficient, co-ordinated and economical system of distribution and to be non-discriminatory in all practices. Ofgem intends that this duty will encourage DNOs to ensure that generators have equitable access to distribution networks.

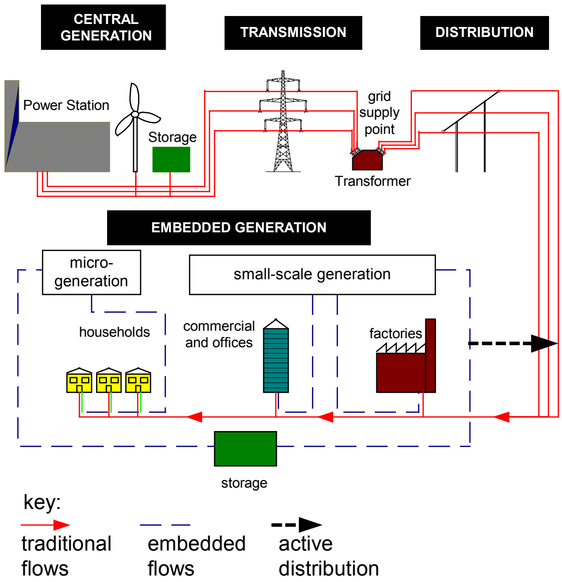
A new model for electricity networks?

All these factors may lead to a considerable increase in 'embedded' electricity generation, where small-scale generating units (which may include renewable sources) are connected directly to the lower voltage distribution networks. This runs counter to the traditional model shown in the figure on page 1, where large generating units are connected directly to the higher voltage transmission network.

Including existing embedded generation, the targets imply that, at most, 20-25 gigawatts (GW) (around one third of total capacity) would be embedded in the distribution networks. However, this level of *"embedded capacity cannot be accommodated on the currently configured networks without significant change"*.[6] Such changes will require the reconfiguration of existing electricity networks into a 'distributed electricity system' that accommodates changed electricity flows (see figure and box opposite).

Distributed electricity system

A distributed electricity system combines electricity from large and small generation units. Large power stations and any large-scale renewables, e.g. offshore wind, remain connected to the high voltage transmission network providing national back up and ensuring quality of supply. Small generators are connected directly to factories, offices, households (e.g. with domestic CHP or PV roofs) and to lower voltage distribution networks (figure below). Electricity not used by customers directly connected to small-scale units is fed back into **active distribution networks** to meet demand elsewhere. Electricity storage systems are being developed that may be able to store any excess generation. These may also accommodate variable output of some forms of generation.



Issues

Policy and regulatory issues

UK energy policy responsibilities are split across a number of government departments, agencies, and regulators. This has led NGOs, industry bodies and think-tanks to suggest that there should be a widely agreed 'vision' of future electricity systems. Some have gone on to argue for a single agency responsible for delivering a sustainable energy system. The current Energy Review (due to report at the end of 2001) may discuss this.

Security of supply is a key element of energy policy (and is currently the subject of inquiries by committees in both Houses of Parliament). The existing electricity transmission system contributes to security of this energy source by ensuring that demand in a specific part of the country is not solely dependent on the availability of generating plant located within that area.

With a higher penetration of renewables, CHP and embedded generation operating in distributed electricity systems, the transmission system might change its role. However, even under this scenario, its integral role would continue in the future electricity system, e.g. providing bulk transfers, network security between regions, and connection of large-scale generating units.

Any attempt by governments to 'pick winners' in the choice of energy technology is fraught with difficulties, and it is widely accepted that the market, on a level playing field, should determine success. Newer technologies offer the hope for cost-effective and environmentally less damaging forms of electricity generation, but since privatisation, investment by the ESI in research and development (R&D) has dropped significantly. R&D in electricity networks has been especially poorly served. Recognising this, the Government provides direct R&D support and is seeking to encourage firms to innovate in this area. For instance, measures include R&D tax incentives, capital grants and market measures such as the Renewables Obligation (see POSTnote 164) which places a legal obligation on electricity supply companies to provide a specific (but increasing) proportion of their electricity from renewable sources.

Market issues

DNOs must facilitate competition in generation and supply. The Government intends that this should lead to growth in embedded generation and renewable energy. However, concerns remain that DNOs do not have the appropriate incentives to achieve this. Some argue that, because output from embedded and renewable sources can be less predictable than from conventional sources, the electricity trading market penalises embedded and renewable energy. Thus, it is argued the present market creates difficulties in meeting the Government's CHP and renewables targets. The market puts a premium on predictable and controllable sources, but environmental benefits are not rewarded. The challenge is therefore, to put in place arrangements which provide appropriate rewards for such benefits.

Charging issues

Distribution charging arrangements present a significant financial barrier to new smaller-scale generation because new entrants must pay the full up-front connection costs. These 'deep' connection charges fall on the first embedded generator to seek connection to the distribution network. However, (with certain exceptions) subsequent generators are not generally faced with these charges. This creates an 'after you' situation where generators hold back to avoid the first entrant charges. DNOs' duties to facilitate competition may require changes in their charges for the connection to, and use of networks, including developing charging structures that:

- reduce the capital cost incurred and encourage additional connections of embedded plant
- recognise and reward the potential benefits of embedded generation (e.g. lower network losses and reduced costs of network investments).
- reward the performance of DNOs in providing secure, reliable and high quality electricity.

Ofgem is consulting on how regulation could help to develop embedded generation. It has stated that initial changes could be in place by April 2002, with more to come following a revision to the distribution price control which comes into effect from April 2005.

Technical issues

Certain energy technologies (e.g. CHP and wind) have variable, intermittent and unpredictable output. Nevertheless, studies have shown (and NGC confirms) that the network could cope readily with 10% of electricity produced from wind[7,8,9], as the system already factors in some variations in demand and unpredictable changes in overall generation (see ancillary services box on page 2). At higher levels however, (perhaps over 20%), intermittency becomes more prominent. Technical responses (inevitably with cost implications) include:

- providing back-up generation facilities
- wider application of electricity storage technologies to smooth out variable outputs.
- development of distribution networks that can handle the two-way flow of electricity (e.g. domestic CHP).

Opportunities for the future

The drive to increase competition, reduce energy prices and environmental impacts have led to the restructuring of the ESI. One outcome might be growth in embedded and renewable generation and development of distributed electricity networks, but this will require innovative approaches to operating the networks. Concerns remain that current regulations obstruct the uptake of new technologies and practices. Without change, the Government's targets for expanding CHP and renewables may be difficult to meet (POSTnote 164). The DTI's Embedded Generation Working Group (EGWG) suggested such changes might include:

- commitment to a co-ordinated programme of work
- rewarding reliability and quality of supply, and the connection of renewable and CHP generation
- adaptation of electricity networks to encourage significant embedded generation.

Overall, in seeking to develop embedded and renewable generation technologies, it should be recognised that this must go hand in hand with changes to electricity networks themselves. The current Ofgem consultation and the Energy Review provides an ideal opportunity to consider ways to create such a new electricity system.

Endnotes

1 Generation of heat and electricity from fuel combustion (mostly gas).
2 NGC and Electricité de France jointly operate the interconnector.
3 POSTnote 163 describes the new electricity trading arrangements.
4 DNOs have no role in the supply (i.e. sale) of electricity. Electricity supply is subject to open competition across Great Britain.
5 10% of electricity generation and 10GWe of CHP by 2010.
6 ETSU (2001) *Technology Status Report: Embedded Generation and Electricity Studies* (www.dti.gov.uk/reneable/embedded.htm).
7 NGC (1999) Evidence to the House of Lords European Communities Committee. *Electricity from Renewables*. HL Paper 78-II.
8 Anderson, D. & Leach, M. (2001) *Intermittency of Generation within Large Energy Systems*, Imperial College.
9 In 2000, wind contributed 0.2% to total electricity generation.

POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of public policy issues that have a basis in science and technology. POST is grateful to Scott Butler and Imperial College Centre for Energy Policy and Technology for the research undertaken in the preparation of this briefing note. A longer report is available on POSTs web site.

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