THE EFFECT OF INCREASING LEVELS OF EMBEDDED GENERATION ON THE DISTRIBUTION NETWORK

ETSU K/EL/00184/REP

Contractors
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First published 1999

EA TECHNOLOGY
UNRESTRICTED

The effect of increasing levels of embedded generation on the distribution network - Final report

by

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Summary

This report was commissioned as part of the EA Technology Strategic Technology Programme under guidance of the Module 5 (Embedded Generation) Steering Group. This report aims to provide information related to the distribution and supply of electricity in the context of increasing levels of embedded generation. There is a brief description of the operating environment within which electricity companies in the UK must operate. Technical issues related to the connection of generation to the existing distribution infrastructure are highlighted and the design philosophy adopted by network designers in accommodating applications for the connection of embedded generation to the network is discussed. The effects embedded generation has on the network and the issues raised are presented as many of them present barriers to the connection of embedded generators. The final chapters cover the forecast of required connection to 2010 and solutions to restrictions preventing the connection of more embedded generation to the network.

Contents

1 Introduction

This report aims to provide information related to the distribution and supply of electricity in the context of increasing levels of embedded generation. There is a brief description of the operating environment within which electricity companies in the UK must operate. Technical issues related to the connection of generation to the existing distribution infrastructure are highlighted and the design philosophy adopted by network designers in accommodating applications for the connection of embedded generation to the network is discussed. The effects embedded generation has on the network and the issues raised are presented as many of them present barriers to the connection of embedded generators. The final chapters cover the forecast of required connection to 2010 and solutions to restrictions preventing the connection of more embedded generation to the network.

The term "embedded generator" in its most general sense covers an extremely wide spectrum of generating plant, both in terms of plant size and plant type. This includes Combined Heat and Power (CHP) plant incorporating gas turbine generators, wind farms and independent power producers connected to the medium voltage distribution network (i.e. 33kV or 11kV) as well as smaller scale domestic or commercial-sized plant, such as inverter-connected photovoltaic systems connected to the low voltage mains supply (i.e. 230 Volts). Within the context of this study, we are mainly concerned with the medium to large size generators. That is to say up to 50MW, with connection at 33kV, but with particular consideration to generators in the 1MW to 10MW size range, which would normally be connected at 11kV. The large generators (i.e. 50MW) tend to be the ones which present the greatest technical challenges, but also tend to have larger budgets with which to solve the problems.

1.1 Background

The DTI's New & Renewable Electricity Studies programme's strategy aim is "to help facilitate access for embedded generation to the electricity supply network, which is fair in commercial terms, not restricted by unnecessary regulations, not subject to inappropriate technical restrictions, and based on cost effective technologies". In recent years the deployment of new and renewable energy technologies has gathered pace, stimulated by the DTI's New & Renewable Energy programme, and the Non Fossil Fuel Obligation (NFFO) whereby a statutory obligation has been placed on the Electricity Industry to purchase power from contracted renewable energy schemes. At the same time, privatisation and the removal of the Electricity Industry's monopoly has opened up the market to private generation, although to date this appears to have had more of an effect with the larger generators (i.e. greater than 5MW). The net result has been an increase in the number of small-scale conventionally-powered embedded generators as well as a heightened level of interest in renewable technologies.

Most new and renewable energy projects generating electricity need to be connected to the electricity distribution network. This is not only a matter of engineering a physical connection coupled with the appropriate safety and network security measures, but it also involves establishing a relationship with the electricity company who own the network, and the traders who will use the network to carry electricity to their customers.

Small-scale generation connected at distribution voltage level does, however, give rise to problems because the UK distribution system was originally designed for unidirectional power flow, taking bulk supplies from the national grid, and has not been designed for the connection of small-scale generation with undefined operating regimes. There are some towns and cities in the UK which can claim to have had local generators in the past (i.e. multiple generator sets in the range 50-100MW). However, an important aspect related to these types of generator is that they were operated under the direct control of the local electricity company. This is not the case for an Independent Power Producer (IPP) operating a current urban generation plant.

Traditionally, the commercial structure of the industry has been designed around centrally dispatched generation via the grid, with electricity being sold by trading through the Pooling and Settlement Arrangement. However, embedded renewable generators and CHP generators may or may not choose to trade through the pool. As these operators account for an increasing proportion of installed capacity, the demand for local connection of embedded generators is set to grow. As a result, there is an urgent need to examine the implications relating to the changing way in which the distribution network is to be used from the point of view of all those involved, and to evaluate the perceived problems and look for potential solutions.

Also, there are technical problems due to protection requirements, fault level limits and quality of supply issues that are creating barriers to the connection of small-scale generating equipment, which is in turn restricting the increased use of renewable energy sources.

2 The Operating Environment for Electricity Companies in the UK

The design principles currently used by electricity companies to accommodate embedded generation and its connection to the distribution network are governed to a large extent to the various regulatory and legal obligations to which they must adhere. Some of these obligations are directly related to embedded generation (such as the non-fossil fuel obligation, NFFO) and so will be familiar to those directly involved in embedded generation. However, most of the obligations are related to the supply rather than the purchase of electricity, which means that these obligations are only indirectly related to embedded generation and therefore those companies and organisations involved in embedded generation with backgrounds outside the electricity industry may not be so familiar with these obligations. It is the purpose of the following sections to explain the general commercial and regulatory factors within which the electricity companies operate and relate this framework to embedded generation.

The operating environment for electricity companies in the UK can be considered to comprise of three elements.

These are:-

- **The legal framework**, i.e. rules created by Government, governed by the Acts of Parliament, etc./
- **The regulatory framework**, as determined by the Public Electricity Supply (PES) Licence and as monitored and regulated by the OFFice of Electricity Regulation (OFFER).
- **The operational framework**, as defined by electricity industry standards, such as the Grid Code and Distribution Code, as well as various Engineering Recommendations (as produced by the Electricity Association, Millbank).

These elements are described in more detail in the following sections:-

2.1 The legal framework

It was the 1983 UK Energy Act[1] which established the right for any person or company to use public networks to transmit electrical energy to third parties or from one location to another. The revision in 1988 of the Electricity Supply Regulations[2] laid down the statutory requirements to operate private generating plant interconnected with public distribution networks. The 1989 Electricity Act[3] then established the structure for the privatisation of the UK electricity industry and transferred ownership and responsibility for the public electricity distribution networks in England and Wales to the Regional Electricity Companies (RECs) and in Scotland to the two Public Electricity Suppliers.

In addition to the Electricity Supply Regulations, the 1974 Health and Safety at Work Act and the subsequent Electricity at Work Regulations (1989) place a duty on all parties concerned to take all practical measures for safety and the avoidance of risks.

2.2 The regulatory framework

The OFFice of Electricity Regulation (OFFER) place tight price controls on the distribution businesses of the electricity companies, whilst at the same time monitoring the quality of supply that customers receive in terms of System Security, System Availability and Quality of Service. OFFER, therefore, provides the framework to allow the electricity companies' supply businesses to operate in a free market whilst providing the consumer with some protection against the extremes or excesses that could possibly take place during the transition to a fully competitive supply market.

2.3 The operational framework

The Electricity Act and the Electricity Supply Regulations led to the production of the Distribution Code[4] and the Grid Code[5], which references documents that state the requirements for all types of connection to public networks.

2.4 The non-fossil fuel obligation (NFFO) and the Scottish renewables order (SRO)

UK Government policy has been to stimulate the development of renewable energy sources wherever they have prospects of being economically attractive and environmentally acceptable, in order to contribute to:

- diverse, secure and sustainable energy supplies;
- reduction in emission of pollutants;
- encouragement of internationally competitive renewables industries.

In March 1993, the Government announced its intention to work towards a figure of 1500 MW of new renewable energy generating capacity by the year 2000. This was followed in November 1997, by the announcement of a review as to what would be necessary and practicable to achieve 10% of the UK's electricity needs from renewables by the year 2010. The Non-Fossil Fuel Obligation (NFFO) was introduced under the Electricity Act 1989 and has been the main instrument for pursuing these developments. The NFFO has also been contributing towards the policy of aiming to return carbon dioxide emissions to 1990 levels by the year 2000.

The Non-Fossil Fuel Obligation is a guaranteed premium market enablement mechanism for the supply of electricity from non-fossil energy sources in England and Wales. Similar market enablement mechanisms exist in Scotland (the Scottish Renewables Obligation) and Northern Ireland (the Northern Ireland NFFO). In this report, these are referred to collectively as the Renewables Obligations.

The purpose of the Renewables Obligations is to create an initial market, so that in the not-so-distant future, the more promising renewables can compete with conventional generation without financial support. To achieve this, prices paid under the Obligations need to converge with prevailing market prices. In order for this to happen, there must be effective competition in the allocation of contracts.

2.4.1 How NFFO operates

The Electricity Act 1989 enables the Secretary of State to make NFFO Orders requiring each Regional Electricity Company (REC) to secure the availability of a certain amount of electricity from non-fossil sources.

The Act establishes a three-fold division of duties:

- the Secretary of State is responsible for making the Orders;
- the RECs are responsible for making the arrangements to comply with the Orders (and contract collectively through their agent, the Non Fossil Purchasing Agency (NFPA));
- the Office of Electricity Regulation (OFFER) is responsible for checking that the arrangements comply with the Order.

The Government decides what size an Order it anticipates, together with which technologies it wishes to encourage based on their judgement at the time as to the most effective way of pursuing market enablement. Specific technologies may be excluded from the Obligations as they approach competitiveness in the open market and do not require financial support, e.g. sewage gas projects were included in earlier NFFOs, but excluded from later rounds.

The RECs invite renewable energy generators to submit details of their proposed NFFO projects to compete in a tender process. Once submitted, these bids must pass the "will-secure" test. This is a test carried out by OFFER where the technical, economic, commercial and legal aspects of the project are assessed to allow OFFER to form a view of a project's ability to contribute to (or "secure") the capacity required by the Order. This is an important element of the NFFO process as failure to comply with the Order is classed as a criminal offence on the part of the RECs.

As well as passing the "will-secure" test, tenders must also compete on price terms with the other tenders in each technology band in order to meet convergence policy. A comparison of the highest prices paid under NFFO 2, 3, 4 and 5 is given in Table 1 below:

Table 1: Comparison of prices paid under NFFO 2, 3, 4 and 5

Technology Band	Highest contracted price paid (p/kWh)			
	NFFO 2 (1991)	**NFFO 3 (1994)**	**NFFO 4 (1997)**	**NFFO 5 (1998)**
Wind	11.0	4.8 (larger schemes) 5.9 (smaller schemes)	3.8 (larger schemes) 4.95 (smaller schemes)	3.1 (larger schemes) 4.6 (smaller schemes)
Hydro	6.0	4.85	4.4	4.35
Landfill Gas	5.7	4.0	3.2	2.9
Municipal and Industrial waste	6.55	4.0	3.4 (Fluidised Bed Combustion) 2.8 (CHP)	2.49 2.9 (CHP)
Energy Crops and Agricultural & Forestry Waste - gasification	-	8.75	5.79	-

Note: prices not adjusted to take account of time value or differences in contract length.

If a project passes the will-secure test and has competed favourably on price terms with the other projects in the same technology band, it will be awarded a contract to generate at its contracted capacity for a period of up to 15 years, receiving its bid price for each kWh generated. The additional costs incurred by the RECs under these contracts, when compared with the cost of fossil generation, are financed through the fossil fuel levy.

Once a project has obtained a NFFO contract, it must then make the arrangements necessary to enable it to commission e.g. obtain planning permission and financing. Obtaining a NFFO contract is therefore no guarantee of a project ever actually being commissioned. In NFFO 3, for example, contracts were let for 626 MW Declared Net Capacity (DNC), although only 300-400 MW DNC are ever expected to commission.

2.4.2 The fossil fuel levy

The NFFO is funded through the fossil fuel levy which previously supported both nuclear and renewable energy generation, but from 31 March 1998 supported renewable energy only. The levy is paid by the supply licensees (based on the aggregate amount charged for fossil-sourced electricity supplied) but is ultimately funded by the final customers for the electricity. The levy rate is set by OFFER and has been 0.9% during the period 1 April - 31 December 1998. As at 31 March 1998, renewable energy had received approximately £557M from the levy.

The levy will continue to support renewables for the duration of the NFFO contracts.

2.4.3 Contracted renewable energy capacity

To date, five Renewables NFFO Orders have been made (NFFO 1 (1990), NFFO 2 (1991), NFFO 3 (1994), NFFO 4 (1997) and NFFO 5 (1998)). Two Orders have also been made under the Scottish Renewables Obligation (SRO 1 (1994), SRO 2 (1997)) and two under Northern Ireland NFFO (NI-NFFO1 (1994), NI-NFFO 2 (1996)).

These Obligations have resulted in 880 projects being awarded contracts (3493 MW DNC), with approximately 630 MW DNC already commissioned. The number of new schemes commissioned is expected to continue to increase over the next few years as NFFO 3, 4 and 5 schemes begin to come on line. Table 2 summarises the status of the renewables obligation.

Table 2 Renewables Obligation Status Summary

Technology	Contracted projects		Commissioned projects as at 30/09/98	
	No	**Capacity (MW DNC)**	**No**	**Capacity (MW DNC)**
Biomass	31	243	5	64
Hydro	141	91	50	35
Landfill Gas	315	673	99	189
Municipal and Industrial Waste	88	1376	13	180
Sewage Gas	31	34	24	25
Wind	274	1076	57	137
Totals	**880**	**3493**	**248**	**630**

2.4.4 The future

The SRO 3 competition is currently going ahead and the Order is expected to be made during early 1999. There is also a Government policy review going ahead to consider the future of NFFO and this is expected to complete shortly.

In conclusion, the Renewables Obligations have been successful in bringing approximately 630 MW DNC on line in the United Kingdom as well as focusing considerable beneficial attention on the renewable energy sector.

3 Current Network Design Principles

The network design principles employed to accommodate embedded generators normally relate to the actual connection of an embedded generator to the existing network rather than to the general planning and design of future network developments. The aim of the design process is to minimise any adverse effects of a particular generator connection on the rest of the distribution network and to do this in the most cost-effective manner possible. This is a reasonable approach to take, since the existing asset base owned by the electricity companies represents a significant financial investment, which has been made in the past, based on the plant providing many years useful service.

Technical designs for generator connection are normally handled by the Planning Departments within the electricity companies. The design engineer, when faced with a generator network connection, will normally consider the following guiding principles.

- meeting the requirements of the Distribution Code (and Grid Code, if appropriate).
- Ensuring the security of supply to other customers is not prejudiced.
- Ensuring the quality of supply to other customers is not prejudiced.
- Ensuring plant and equipment on the distribution system operates within its rating.
- Designing the connection to meet the appropriate technical standards
- Ensuring that the statutory requirements set out in the *Electricity Supply Regulations 1988* are met. *Regulation 26* specifically covers interconnected supplies and their use.

3.1 Distribution code requirements

The Distribution Code, approved by the Director-General of Electricity Supply, defines the technical aspects of the working relationship between the Public Electricity Supplier (PES), Distribution System and to those connected to it. It is in two parts, the Distribution Planning and Connection Code (DPC) and the Distribution Operating Code (DOC). It contains detailed requirements related directly to embedded generators and deals with technical aspects concerning supply of electricity and the use of the distribution network for the transport of electricity. The Distribution Code is given legal authority by the provisions of licences issued under the Electricity Act 1989.

3.2 Grid code requirements

The Grid Code, also approved by the Director-General of Electricity Supply, defines the technical aspects of the working relationship between National Grid Company (NGC) and all those connected to the NGC Transmission System. In addition to supplying the PES with details of Embedded Generating Plant there is a requirement to provide information to NGC, under the Grid Code. An electricity company can not connect a generator to the network until approval has been obtained from NGC under a master connection use of system agreement.

3.3 Engineering recommendations

3.3.1 Security of supply

The main document relating to Security of Supply for network planners is the industry-standard Engineering Recommendation P.2/5 Security of Supply 1978,[6]. P.2/5 is a minimum standard and provides a robust mechanism for establishing the reliability of the overall distribution system through deterministic enforcement of plant redundancy levels. Historically, engineering strategies have been directed at providing electricity supplies meeting the security standards contained in Engineering Recommendation P.2/5. Nowadays, however, electricity companies are able to provide a standard of supply much better than the minimum standard specified in P.2/5. As a general planning document, P.2/5 does make some reference to generation. However, these refer to older, historical town or city generating plant, which now no longer exist. Certainly, these references are not really applicable to the modern type of generator that an IPP generator might be using under the current operating regimes.

3.3.2 Quality of supply

This is covered by two principal documents, the first covering the limits of supply voltage fluctuation and the second covering the purity (harmonic content) of the supply frequency. However, it is absolute voltage and voltage fluctuations which tend to be the more important considerations. Engineering Recommendation P.28[8] ('Planning limits for voltage fluctuations caused by industrial, commercial and domestic equipment in the United Kingdom') sets defined limits on the level of voltage fluctuation caused by the embedded generator. This is particularly important where the generating plant is run-up to speed as a motor connected to the REC's system, where any associated disturbance must be within the limits stipulated in P.28. Engineering Recommendation G.5/3[7] ('Limits for harmonics in the United Kingdom Electricity Supply System') sets defined limits on the level of harmonic distortion allowed to the fundamental 50Hz supply frequency. When connected to the network, the embedded generator must not cause harmonic distortion to exceed the limits set out in G.5/3.

3.3.3 Plant and equipment ratings

Ratings for new plant and equipment are specified in accordance with existing plant loading, with important consideration also given to the anticipated future increase in operational duty due to natural load growth. Obviously, subsequent addition of embedded generation plant can dramatically alter the operational duty of existing plant, especially in terms of fault current handling and protection requirements. The *Electricity at Work Regulations 1989, Regulation 5 - Strength and capability of electrical equipment* sets out the statutory obligations with regard to the rating of electrical equipment.

3.3.4 Technical standards for network connection

The main document covering the connection of embedded generators to the electricity distribution network is Engineering Recommendation G59/1 (Amendment 1),[9]. G59/1 specifies the requirements electricity companies place on generating plant requesting network connection as an embedded generator including the basic safety and technical requirements in respect of the interface between the electricity company network and embedded generator. G59/1 is supported by Engineering Technical Report ETR 113[10]. ETR 113 is the technical document which provides guidance on the methods of meeting the requirements of G.59/1. Engineering Recommendation G75[11] covers the connection of generators above 5MW and 20kV connection voltage. There is nothing particularly significant by the choice of 5MW (or 20kV) as a limiting factor in the above documents other than that at the time the documents were produced it was envisaged that generators greater than 5MW would more likely be connected at higher voltages.

3.4 Technical considerations for network connection

The main technical considerations relating to embedded generation can be broken down into three main areas:

3.4.1 Generating plant and export requirements

The characteristics of the generating plant and export requirements (some sets may not actually export to the system) need to be detailed.

- Connection Voltage.
- Plant Rating.
- Type of Generating Plant - synchronous, asynchronous etc.
- Type of Prime Mover.
- Operating regime of generation, e.g. continuous, intermittent, peak lopping.
- Method of voltage control.
- Generator transformer details.
- Requirements for top up supplies and/or standby supplies.
- Export requirements (some sets may not export to the system).

3.4.2 Effect of the generation on the distribution network

The connection of the generator to the PES's distribution network must be designed so that unstable operation does not occur. Key points that need to be addressed are:

- Fault level contribution.
- Active and reactive power flows.
- Network Voltage Implications and requirements (if any) for automatic voltage control equipment.

3.4.3 Interface arrangements

The interface arrangements need to contain information other than the physical electrical connection of the generator.

- The means of synchronisation between the PES and the User.
- Earthing Arrangements.
- The method of connection and disconnection which are to be employed.
- The method employed to prevent islanding where islanding is not allowed.
- Precautions to be taken to ensure the continuance of safe conditions should any earthed neutral point of the Generators System operated at HV become disconnected from earth.
- Protection arrangements to satisfy G59/1: overload and overcurrent, earth faults, phase unbalance or loss of phase, over and under voltage and over and under frequency.
- Metering facilities.
- Connection and safety management agreements.

3.5 Application of the requirements by electricity companies

The previous sections have outlined the legal, regulatory and operational frameworks that electricity companies must comply with when connecting additional embedded generating plant to the distribution network.

The report will now expand upon the design philosophy adopted by network designers when considering how best to accommodate new applications for connection to the existing network. Under the terms of the Public Electricity Supply Licence, all electricity companies are required to respond to a formal request for connection by an applicant by providing an offer for connection. The detail of exactly how this is dealt with varies from one electricity company to another. However, as an aid to understanding the overall process, from point of application to provision of a firm offer for connection, this report presents a generalisation of the sequence of events together with the key stages and decision processes involved. The information within this section has been compiled through direct consultation with a number of the UK electricity companies.

3.5.1 Approach

Initially a procedural flow chart was drawn up to summarise in a general manner the internal steps taken by a typical electricity company when dealing with a request for connection. This was done in consultation with members of the steering group who preside over EA Technology's Strategic Technology Programme (STP) Module 5 - Embedded Generation. These members represent the following UK electricity companies:

Eastern Electricity plc
East Midlands Electricity plc
London Electricity plc
Midlands Electricity plc
Manweb plc (inc. ScottishPower plc)
South Western Electricity plc
Yorkshire Electricity plc

Based on the resultant flow chart, a questionnaire was drawn up requesting more specific details about how individual electricity companies dealt with the different stages on the flow chart. The questionnaire was also tailored with the assistance of STP Module 5 steering group members so that its structure represented a balance between identifying different company approaches to handling generator connection requests, whilst at the same time respecting areas of commercial sensitivity. A copy of the questionnaire is contained in Appendix I. The flow chart itself was included with the questionnaire to give recipients the opportunity to modify it if it was not considered appropriate to their own procedural approach.

Copies of the questionnaire were distributed to all the PES representatives on the Distribution Code Review Panel in order to obtain the views from as many of the UK electricity companies as possible. Hence the companies contacted were:

Eastern Electricity plc
East Midlands Electricity plc
London Electricity plc
Manweb plc (inc. ScottishPower plc)
Midlands Electricity plc
Northern Electricity plc
NORWEB plc
SEEBOARD plc
South Western Electricity plc
Southern Electricity plc
Swalec plc
Yorkshire Electricity Group plc

At the time of writing this report nine of the above twelve companies had responded and their input has been included in the questionnaire findings. The following sections summarise the results obtained from the questionnaire.

3.5.2 Questionnaire results

For reasons of confidentiality, company anonymity will be maintained and the summary provides a generalisation of the responses received. Where specific exceptions are considered to be relevant, these are noted, however individual companies are not identified.

3.5.2.1 Procedures for dealing with requests for embedded generator connection

Figure 1 shows the final version of the procedural flow chart depicting the general sequence of events and tasks for dealing with a request for generator connection. This incorporates the modifications fed back from the questionnaire replies. As such it is believed to provide a reasonably accurate summary of the application process currently employed by the majority of electricity companies. The process commences with a formal request from an applicant who wishes to apply for a connection to the network. Seven out of the nine companies who responded have a standard application form or questionnaire that must be completed by the applicant prior to the request being considered by the electricity company. The level of detail requested on the application forms, including the technical parameters for the generation plant, varies considerably from one company to another. Of the seven application forms received, the length varied from 2 to 19 pages; however some included more detailed background/explanatory information to assist the applicant in making the application.

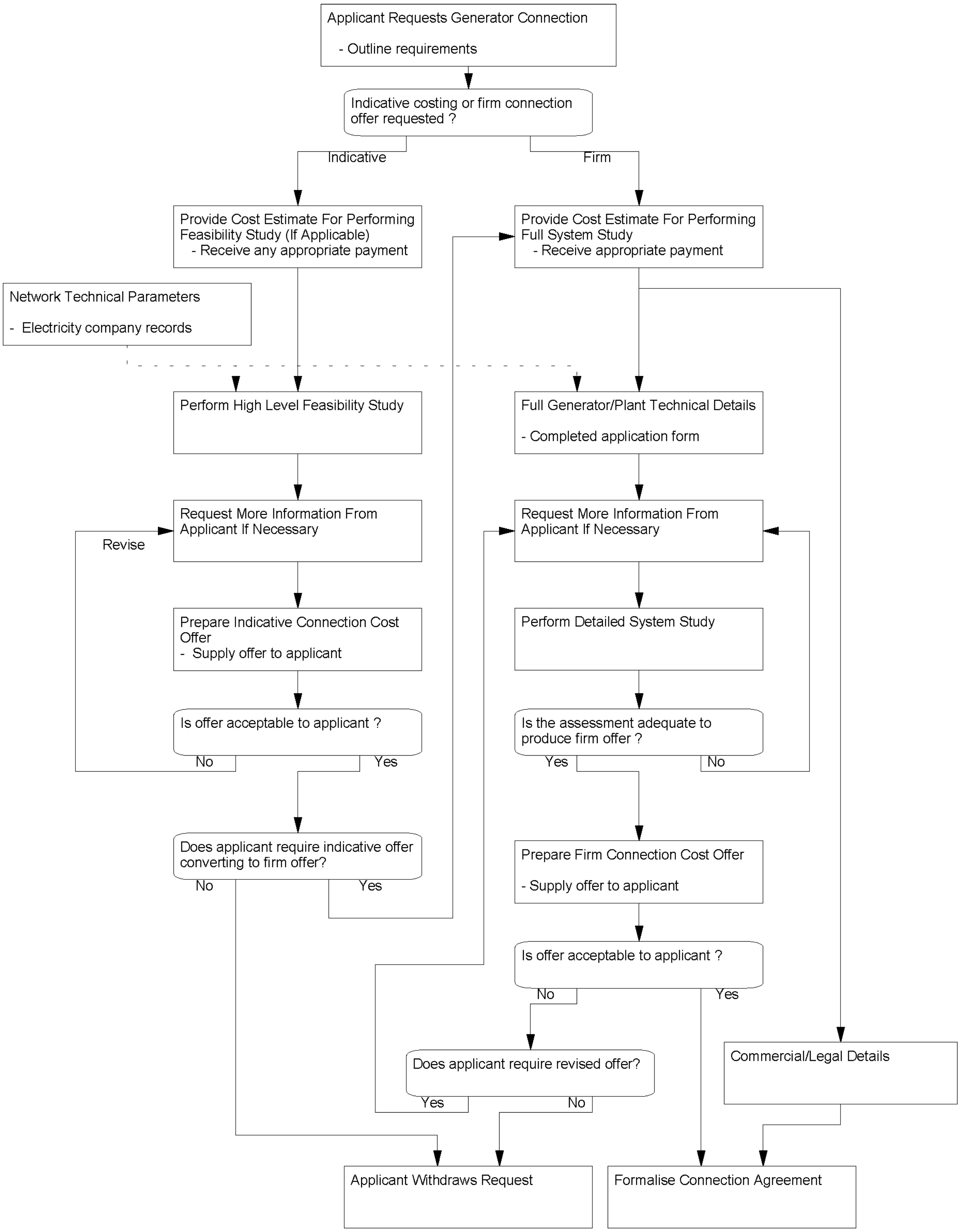


Figure 1. Procedural flow chart for dealing with requests for embedded generator connection

The type of request that an applicant will make can broadly be divided into one of two categories:

1) *Indicative costing* for connection required
2) *Firm offer* for connection required

An indicative costing or feasibility study is normally requested when the applicant only wishes to obtain an idea of the approximate cost and practicality of connecting a generator to the network at a specific point for budget purposes only. The electricity company will usually issue a conditional offer that will include certain caveats and assumptions that would need to be addressed in more detail before a firm offer of connection could be made. Less technical detail about the applicants proposed installation will be required for an indicative costing than for a firm offer, hence it may not be necessary to supply all the information requested in the standard application form in order to obtain an indicative costing.

An application for an indicative costing may subsequently be promoted to an application for a firm offer. If an applicant receives an indicative cost estimate that is deemed acceptable, he may opt at a later date to take the application further and have the study resumed - but in greater detail - with a view to obtaining a firm offer of connection. If the applicant had only provided the generation equipment information in-part in the first instance, (i.e. for an indicative costing) then it may be necessary for the electricity company to obtain more detail from the applicant before the request can proceed.

If the applicant requests a firm offer of connection, then the electricity company will perform a full system study to examine all the technical aspects of the proposed connection in detail, before issuing a formal connection offer and quotation for the connection costs involved. When the system study has been completed to the required level of detail, a firm offer of connection will be made to the applicant. If it is acceptable to the applicant then a formal connection agreement will be entered into. If it is not acceptable to the applicant, then the applicant may choose to withdraw the request, or alternatively re-submit it with revisions in order to obtain a modified offer of connection that is acceptable. If the application has some unusual features, it may be necessary for the electricity company to seek further information from the applicant to enable them to complete their task. This process is depicted on the flowchart and the number of iterations around the loop will depend largely on the circumstances appertaining to the individual application.

In parallel with the decision-making processes carried out by the network designer, the electricity company will also have to make the appropriate commercial and legal arrangements, such as construction contracts, local planning consent etc. Although these will also be incorporated into the formal connection agreement, they are beyond the scope of this study. Within the majority of the companies the application process is technically driven. Only one company reported that the process was commercially driven, while two others indicated that the process was both technically and commercially driven.

3.5.2.2 Applicant's history

In arriving at a suitable connection scheme, none of the companies decision processes are influenced by the technical competence, capabilities or past experience that the applicant may possess in installing and operating electricity generation equipment. The technical requirements are the same for all applicants regardless of background knowledge. However, in some instances, the amount of assistance and support offered during the application process may be varied as appropriate to the needs of the applicant.

3.5.2.3 Point of connection

In seven out of the nine respondent companies, the exact physical point of connection to the network is decided by an Electricity Company Engineer whose knowledge and experience is used to determine the most appropriate position, rather than simply taking the applicants request at face value. In all cases, should a more appropriate point of connection than the one specified by the applicant become apparent during the early stages of the application review, then the electricity company would convey this fact to the applicant as a matter of course.

3.5.2.4 Technical details required

When examining the level of generator/interface plant technical details that are required there is some considerable contrast in what parameters are considered essential, desirable or not required between individual companies. There are also significant differences in the classification regimes that are used to group generator installations in order to assess connection requests, i.e. groupings based on generator capacity (MW) and/or connection voltage. Table 3 illustrates the different criteria used by the seven companies that responded to this question in order to determine the level of detail required for the application.

Table 3. Examples of breakpoints used by different companies generator classes that determine level of technical detail required for application.

Company No	Group 1 (less detail required)	Group 2	Group 3 (more detail required)
1	<11kV	11kV	33-132kV
2	<1MW, 415V	>1MW, >415V	
3	other kV	132kV	
4	<10MW, 11kV	33kV	≥50MW, 132kV
5	1MW, 430V	5MW, 11kV	>5MW, ≥11kV
6	<0.15MW	>0.15MW	
7	small/simple	large/complex	

Clearly the level of detail required by an electricity company will be dependent on a wide range of factors including: the geographical location of the intended connection (i.e. rural or inner-city), the type of application (i.e. indicative costing or firm quotation), and the network configuration itself. Hence it is to be expected that some companies will require a different set of generator technical parameters to others.

Due to the diversity of the questionnaire replies, it is not possible to draw any further conclusions in this area without a more detailed analysis which would be beyond the scope of this report. Should there be a requirement to further harmonise the application process between electricity companies, this subject may be worthy of further consideration at a later date, conducted as a separate exercise aimed at establishing the relative importance of the detailed technical parameters.

3.5.2.5 Intended mode of operation

Table 4 summarises the response to the question concerning information appertaining to the applicants intended mode of operation. The table indicates how the electricity companies rank the importance of information relating to the issues listed in the question. Maximum import/export requirements and level of security are issues that all the companies consider to be essential. Information relating to load management arrangements in the event of a breakdown or scheduled downtime is considered to be less important overall.

Table 4. Importance attached to information regarding the applicants intended mode of operation

Information required from applicant regarding mode of operation	Essential	Desirable
Maximum import/export requirements	9	
Percentage of full rated capacity that the generator will typically operate at	4	3
Anticipated output regime (i.e. continuous, intermittent, peak lopping)	6	3
Requirements for top-up or standby supplies (MVA)	8	1
Load management arrangements made to prevent voltage exceeding statutory limits when the generator is scheduled to be off line (i.e. for maintenance)	3	2
Load management arrangements made for unscheduled stoppages i.e. breakdown	3	2
Level of security required	9	

3.5.2.6 Start of the application process

Once an application for generator connection has been received, Table 5 summarises the information obtained regarding the start of the application process. All the electricity companies who responded to the questionnaire charge a fee for performing a full system study leading to a firm offer and quotation for connection. Seven of the nine companies also charge a fee for performing a feasibility study to provide an indicative costing.

The date determined as the effective start date for the processing of the application varies between companies. In all cases, sufficient information must have been received from the applicant, together with an appropriate fee, if applicable, prior to the effective start date. When these conditions have been satisfied, most companies treat the request for a firm offer as the effective start date, however two companies treat a request for an indicative quote as the start. One company employs a two-stage approach with separate start dates for indicative and firm offer requests. Only two companies report that they formally notify the applicant in writing of the effective start date, however other companies may make the applicant aware informally or upon request.

Table 5. Commencement of application process

Start up Procedures	Company								
	1	2	3	4	5	6	7	8	9
Fee charged for Indicative Costing (Y/N)	N	N	Y	Y	Y	Y	Y	Y	Y
Fee charged for Firm Offer/Quotation (Y/N)	Y	Y	Y	Y	Y	Y	Y	Y	Y
Effective Start Date advised formally in writing (Y/N)	N	N	N	N	Y	Y	N	N	N
Effective Start Date taken from commencement of **I**ndicative or **F**irm Study	F	F	I	I&F *	I	F	F	F	F

*Two stage approach adopted with two separate start dates for each of the two stages

3.5.2.7 Feasibility studies and full system studies

The next section of the questionnaire deals with system studies and the level of detail associated with a feasibility study to produce an indicative costing, and a full system study to prepare a firm offer and quotation. The objectives and output for each type of study are summarised below:

Feasibility study - for indicative costing

Objectives - To perform a high level study to ascertain the effects of the proposed generator connection on the electricity company's distribution system and to highlight any modifications required to the network, or its operation. It should identify, at an early stage, any significant constraints that would render the proposed connection in its existing form non-feasible.

Output - A proposed connection arrangement together with an indicative cost estimate is provided for the applicant. This will usually contain caveats together with any assumptions that have been used to produce the indicative costing. It may also include the preliminary results of fault level and voltage profile studies as well as brief details of any network reinforcement that is anticipated.

Full system study - for firm offer of connection

Objectives - To perform a detailed connection study to establish the precise system constraints and produce a working connection scheme. The detailed study will involve a more thorough examination of fault levels and voltage profiles than the initial feasibility study. It will also address issues associated with load flow, protection, stability, synchronisation and interlocking. Consideration will also be given to network modifications, including equipment replacement, substation layout, overhead line/underground cable routes and operational arrangements.

Output - The exact point of connection will be established with a technically feasible scheme for connection. The applicant will be advised of the commercial and technical arrangements with a formal written quotation for the connection charges together with a draft connection agreement. It is possible that a firm offer for connection may also contain some caveats relating to issues that are beyond the electricity company's control, e.g. way leaves, easements, local authority planning permission.

Table 6 contrasts the issues addressed by the different electricity companies for the two types of system study.

Table 6. Issues addressed for indicative costings and firm connection offers by different companies.

Issues	No. Companies to Consider Issue	
	Indicative Costing	Firm Offer
Location	9	9
Connection arrangement	7	9
Existing generation capacity	7	9
Control - synchronisation and interlocking	0	9
Protection	5	9
Earthing	0	9
Fault level	9	9
Stability	4	8
Voltage control	5	9
Islanding	1	8
Load flows	6	9
Operational implications	4	8
Impact on NGC	3	9

3.5.2.8 Barriers to connection

A range of technical problem areas were identified that were seen to create barriers to embedded generator connection. The effect of increasing fault level was of particular significance. Often switch gear replacement would be required in order that the network be able to cope with the increased fault level brought about by the additional generation capacity. In instances where the entire cost of such an upgrade would need to be borne by a single applicant this could make connection uneconomic, particularly at lower voltage levels.

Other barriers cited included:-

1. Voltage control - particularly at lower voltages. This could, in part, be due to existing voltage control methods not being able to cope with the larger voltage

variations on the system, hence reducing their ability to maintain proper voltage control within the statutory limits. This could lead to voltage rise on 11kV feeders and rural systems. Also there is the possibility of other customers on the same voltage level experiencing step-change voltage fluctuations in the event of the generator tripping.

2. Reverse power flow through transformers if the locally installed generation capability exceeds local demand. This could, for instance, lead to power flow from the 11kV network to the 33kV network if the load on a 33/11kV substation fell below the generation output. This situation is highly undesirable as the network was not originally designed to operate in this manner and transformer protection systems and some voltage control methods can be defeated under these circumstances.

3. Protection grading can be adversely affected.

4. Switchgear can become over-stressed for making and breaking duty.

5. Stability problems may occur at 132kV.

6. The export power from the embedded generator can be restricted by the voltage profile and/or thermal rating of the system local to the point of connection.

3.5.2.9 Documentation consulted

There is a wide range of documentation that may be referred to as part of the application assessment process. The documents cited on the questionnaire returns where:-

1. The Distribution Code 1990.

2. Engineering Recommendation G59/1, Amendment 1, "Recommendations for the Connection of Embedded Generating Plant to the Regional Electricity Companies' Distribution Systems", 1995.

3. Engineering Recommendation G74, "Procedure to Meet The Requirements of IEC 909 For The Calculation of Short Circuit Currents In Three-phase AC Power Systems", 1992.

4. Engineering Recommendation G75, "Recommendations for Embedded Generation Plant to Public Electricity Suppliers' Distribution Systems above 20kV or With Outputs Over 5MW".

5. Engineering Recommendation P2/5, "Security of Supply", 1978.

6. Engineering Recommendation P28, "Planning Limits for Voltage Fluctuations Caused by Industrial, Commercial and Domestic Equipment in the United Kingdom", 1989.

7. Engineering Technical Report ETR 113, Revision 1, “Notes of Guidance for the Protection of Embedded Generating Plant up to 5MW for Operation in Parallel with the Public Electricity Suppliers’ Distribution Systems”, 1995.

8. Engineering Technical Report ETR 120, “Calculation of Fault Currents in Three-phase AC Power Systems (Application Guide to Engineering Recommendation G74)”, 1995.

9. Internal Codes of Practice produced by individual electricity companies.

3.5.2.10 Modifications to network and operational practices

Question 4.6 enquired as to what extent companies would be prepared to modify their network operations in order to reduce the cost of connection to an embedded generator applicant. All the companies indicated that any modifications resulting in detrimental effects on the security and quality of supply to their existing customers would not be considered acceptable, and that if any such effects had to be tolerated that they would have to be very slight and remain within statutory limits. In general, the companies were willing to look at changes in system operation providing that the costs associated with the changes were met by the applicant and that the changes would not lead to unacceptable network operation.

3.5.2.11 Concurrent applications

There is sometimes a need to deal with concurrent applications where more than one application is received for connection to the same part of the network. This can lead to additional problems, particularly in situations where the existing network would only be capable of accommodating one or other of the two applications without significant re-enforcement. However, there are circumstances where the work required for the first generator makes it possible for a second generator connection with reduced costs as the necessary work has already been completed for the first. If both generators wish to proceed and major expenditure is required in order to facilitate the two connections, then this raises the question of who incurs the cost of the reinforcement/modification work ?

At present, most of the companies deal with this issue on a ‘first-come, first-served’ basis. Under the ‘first-come, first-serve’ basis, the second applicant would normally incur any reinforcement costs over and above those required to provide a connection for the first applicant. There would appear, however, to be differences in the way this operates between individual companies. In most companies, ‘first-come’ means the first applicant to enter into a formal connection agreement; in other companies it can relate to the effective start date for the commencement of the application process. In situations where one application could directly affect another, the applicants are usually made aware of the situation and a ‘contract race’ may result. Two other alternative approaches for dealing with this aspect were also reported. One company would withhold making its offer of connection to the second applicant until the period of validity of the offer made to the first applicant had expired, assuming the first applicant had not accepted the offer. Another company would seek permission from both applicants to disclose details of their connection request to the other, and for the applicants to then decide if a ‘combined application’ would be more appropriate as an alternative to a contract race.

3.5.2.12 Technical feedback to applicant

The level of technical detail fed back to the applicant when a formal offer of connection is made varies considerably from one electricity company to another. In some instances, because the applicant has paid for the system study to be performed, he will receive a full report by default. Other companies will only supply information relating to the cost of any plant modifications that are required, or share information on request, when specifically asked by the applicant.

4 Effects of Embedded Generation on the Existing Network

Many of the effects caused by connecting generation to the distribution network cause difficulties related to the planning and design of the network. Historically, the distribution network has been designed to accommodate power flow from the Grid Supply Points downwards through tiers of networks operating at lower voltages to the electricity consumers. The network is designed to meet the needs of normal operation, fault conditions and abnormal operation, e.g. when the network has been re-configured to accommodate routine maintenance. Incorporating generation within the distribution network adds another dimension to the network design process.

A number of technical barriers to the connection of embedded generators have already been identified in the analysis of the questionnaires. To recap, the barriers cited in the questionnaires included:

- Fault Level (including make and break duty).
- Voltage Control.
- Reverse Power Flow.
- Protection Grading.
- Stability at 132kV.
- Voltage Profile.

A discussion group was held with four of the participating electricity companies to identify the effect embedded generation has on the existing network. The issues which are of primary concern include:-

- Network Capacity.
- Network Security.
- Power Quality.
- Voltage Regulation.
- Earthing.
- Fault Level.
- Asset Utilisation.
- Losses.

These issues are of relevance at both LV (230V) and MV (11kV & 33kV) voltage levels, although the relative impacts of the different network design issues are likely to vary, depending on the network voltage level. In the following sections the above issues are each described in turn. However, it is important to note that many of the issues are inter-related and the design often evolves as a trade-off between the competing design parameters.

It is also worth re-stating that the design of the network connection for any generator must be achieved at minimum cost, whilst meeting all of the relevant legal, regulatory and safety requirements.

4.1 Network capacity

Network capacity is primarily dependent on the transformer, switchgear and cable/overhead line equipment ratings. The connection of an embedded generator to the network can result in one or all of the above plant items exceeding their defined ratings. In order to accommodate the embedded generator items of plant which would exceed their ratings would need to be uprated.

However, in some circumstances the connection of an embedded generator may delay or postpone network reinforcement by meeting the power demand locally and therefore reducing the load on the network. To achieve this the embedded generator must be available at times of excessive or peak demands in the associated network.

4.2 Quality of supply

The term ‘quality of supply’ covers a wide range of issues, including supply outages and short term interruptions, power quality and customer service. Network security and power quality will be covered separately.

4.3 Network security

Network security is one of the primary design factors for any distribution network. There are frequent debates about how embedded generation effects network security. P2/5 is the primary design document related to network security and at present does not allow much in the way of positive contribution to security from embedded generation, unless multiple sets within one scheme are considered, i.e. a situation similar to multiple sets in a conventional power station.

Network security is directly related to the length and condition of cables and overhead lines, the number of transformers, network topology and protection and switchgear arrangements. Embedded generation can in some circumstances be seen as an alternative to transformer capacity. However, this would only be the case if the costs of either option are borne by the same party. A cost benefit study is important as additional transformer capacity is typically cheaper than generation capacity.

Hidden loads which exist on sites which have embedded generation add additional uncertainty to the planning process. The local electricity company’s network normally only sees the difference between the on-site generation and on-site load. However, on occasions when the on-site generation is unavailable the network would see the full on-site load.

4.4 Power quality

Power quality normally relates to the electrical properties of the electricity supply, namely the voltage and current waveforms. This includes frequency, the steady state rms voltage magnitude, the harmonic current content, power factor, etc. Of these, voltage regulation is probably most important and is therefore treated separately.

4.5 Voltage regulation

The voltage profile on any network is dependent on the source voltage, the network impedances and the network loads. Networks are designed such that under worst case conditions, the voltage magnitude on any part of the network is within the statutory limits. In some cases, depending on the size of the generator and the point of connection within the network, the embedded generator can make the voltages on the network higher than the statutory voltage. This effect is most marked in the weak rural 11 kV networks with lines having relatively high impedances.

Statutory voltages in distribution networks are maintained by controlling the voltage at source substations using on-line tap changers with Automatic Voltage Control (AVC) relays. The voltage range of existing equipment particularly at the low end may not be sufficient to accommodate the effect of embedded generation.

Another factor affecting quality of supply is the susceptibility of existing loss-of-mains protection relay settings to nuisance tripping of embedded generators. The sudden loss of an embedded generator will often produce undesirable voltage fluctuations.

4.6 Earthing

The Electricity Supply Regulations (1988) repeat the long standing requirement for all public distribution networks to be connected to earth as close to the source as possible. This is to prevent long term overvoltages and minimise the risk of electrical shock by providing predetermined paths of earth leakage current to operate protective devices.

Most 11kV embedded generators do not normally have their neutral point earthed when operating in parallel with a distribution system. To earth a generator in parallel with PES system earths will generally require a detailed analysis and it is necessary to ensure that there will be no circulating current that may interfere with protection and communication systems.

4.7 Fault level

Fault level is not just an issue for interconnected networks, it is a problem which is inherent in any area of dense, high, load such as urban town and city centre areas and is therefore normally associated with cable networks, but can still be a problem on overhead lines. If the resultant fault levels exceed the switchgear, cable or overhead line ratings, then the appropriate plant must be uprated. In addition the increased fault level may make it necessary for other customers to uprate equipment. When considering fault level it is necessary to consider both the making and breaking duty that will be required.

4.8 Asset utilisation

Another important aspect in network design is the aim of maximising the utilisation of the assets used in the distribution network. These assets represent a significant investment and so it is important that these assets are utilised as effectively as possible. Embedded generation generally tends to reduce asset utilisation, since the network needs to be designed to cope with situations in the future when the generator may not be available (both short-term and long-term unavailability).

4.9 Losses

Losses on a given network with embedded generation connected can be high or lower than without the generation. This will largely depend on the location of the embedded generators with respect to the major loads and the power flow on the network.

5 Forecast of Required Connection to 2010

Embedded generation comprises a mixture of renewable and non-renewable technologies, while large-scale hydro stations are renewable but linked to the grid like conventional power stations, not so embedded. Indeed, while many people think of embedded generation as synonymous with renewable energy, large-scale hydro accounted for 54% of renewable energy generated in the UK in 1997.

Figure 2 illustrates this point; note that some renewable generators export all their power to the network, while others such as Combined Heat and Power (CHP) plant will produce much of their power for use on site, importing from the network to make up shortfalls and exporting when there is excess capacity on site. Most CHP plant runs on non-renewable gas or oil, but a few CHP generators use renewable fuels.

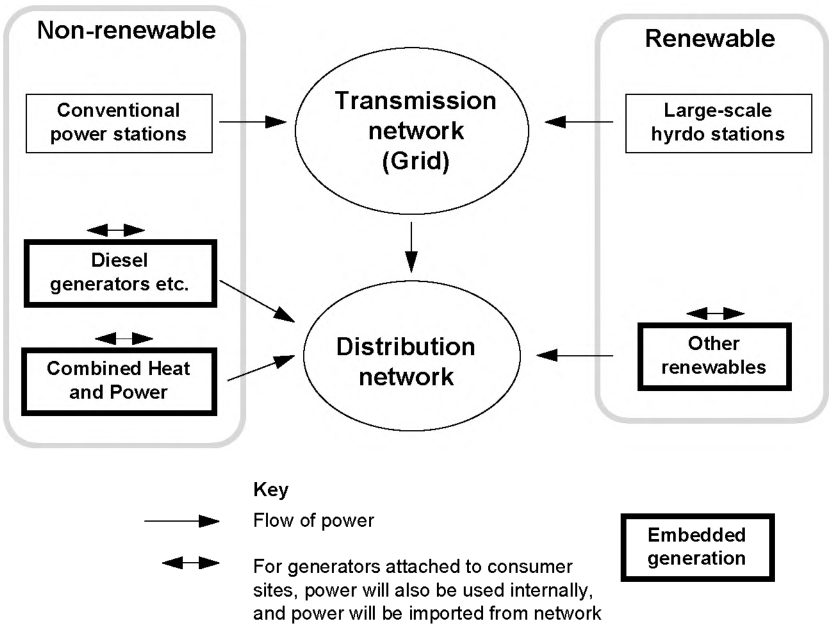


Figure 2. Relationships between different types of generation and networks.

Renewables are also used to produce heat - this includes renewable gas, solar energy, waste incineration, etc. While this is not considered further here, it is worth noting that statistics, targets etc. for renewable energy often include heat as well as electricity.

Many reports now use the term 'new and renewable energy' rather than just renewable energy. This encompasses types of energy production which are not strictly renewable, such as municipal waste incineration which includes materials such as plastics from non-renewable sources. However, these 'new' types of energy do not use fossil fuel directly, but exploit previously untapped resources, and have many of the technical characteristics of renewable energy generation. In this report, 'renewable' will mean 'new and renewable' in this sense.

The capacity of 'embedded generation' needs to be clearly defined. Many buildings have standby diesel generators which are only used when the network supply fails. A few of these are used for peak lopping on site to reduce maximum demand charges, but do not export power to the network. Wider use of such generation to help to meet peak demand via the distribution network had been considered in the UK, but does not happen at present. On industrial sites with CHP generation, most of the power is used on site but a significant proportion may be exported. Some very small-scale renewable generation, such as photovoltaic arrays, can only be used on site as they are not connected for export. Renewable generators, because they rely on natural resources such as wind and rainfall, typically operate with a load factor well below 100%; around 25% for wind, 33% for hydro and 60% for biofuels. This means that generation capacity is usually measured in Declared Net Capacity (DNC), which is the equivalent capacity of base load plant that would produce the same average annual energy output - in other words, average capacity.

For the purposes of this report, embedded generation may be defined as electricity generation which is connected to the distribution network and exports a significant proportion of its output to the network. This distinguishes it from conventional generation connected to the transmission network. In terms of capacity, transmission network connections are typically of the order of >50MW. Apart from large-scale hydro which is connected to the transmission network, renewable generators and CHP are well below this size, with large wind farms in the order of tens of MW while most other generators are of the order of a MW. For UK energy statistics[12], small-scale hydro is defined as coming from companies with a *total* generating capacity below 5MW DNC.

Statistics on renewable electricity generation[12] include all the net generation from the plant, so includes electricity used on site. In most cases there is no on-site use; the exceptions include generation on farms such as chicken litter gas generation, where power may be used locally for lighting etc. Photovoltaic generation is also usually used on site, but the amounts are at present too small to be included in the UK statistics. Overall, the amount of renewable generation used on site is probably insignificant. Both capacity in Megawatt electric (MWe) DNC, and generation in Gigawatt hour (GWh), are given in[12]. From the definition of DNC, the DNC and generation values for each type of generator are in roughly the same proportions. It might be expected that the total energy generated in a year would be the DNC multiplied by the number of hours in a year, i.e.

$$\text{annual energy generation GWh} = \text{power } MW_{DNC} * 8760/1000$$

However, in general this is not the case because some plant is not operational for a whole year, and the factors applied to maximum output to give DNC output (for example 0.43 for wind) are for an average weather year.

5.1 Current situation

5.1.1 Renewable electricity generation

Information on renewable energy in the UK is maintained by ETSU in the RESTATS (REnewable Energy STATisticS) database. Current and past generation is described in Chapter 10 of[12]. In total, 2.1% of electricity was generated from all renewables (7,341GWh out of 345,342GWh). Excluding large-scale hydro in 1997, i.e. embedded renewable generation, the figure is 3,378 GWh, or 1.0%.

Most of the generation is from wind, water and biofuels. Despite a lot of interest, photovoltaics contributes too little to be included in the statistics; it is growing at just 8.5 kilowatt electric (kWe) per year. Similarly wave power is insignificant; an experimental plant on Islay in the Hebrides is due to be decommissioned this year, having been running since 1991.

Figure 3 shows the increase in significant renewable generation capacity, excluding large-scale hydro and therefore embedded.

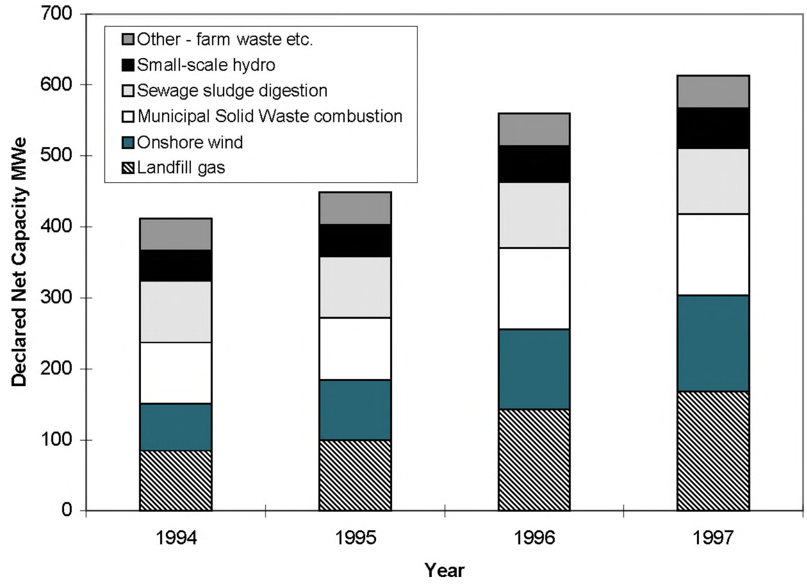


Figure 3. Increase in renewable generating capacity from 1994 to 1997.

The same information is given numerically in Table 7. For comparison, the large scale hydro capacity was 1483 MWe in 1997. Most of the generation, 69% in 1997, came from biofuels. Overall, capacity increased by 9.5%, with wind, small-scale hydro and landfill gas showing the largest increases.

Table 7. Increase in renewable generating capacity from 1994 to 1997.

Declared Net Capacity (MWe)	1994	1995	1996	1997	Change 96-7
Onshore wind	65.7	85.1	113.0	135.4	19.8%
Small-scale hydro	42.2	44.3	50.8	55.8	9.8%
Biofuels:					
Landfill gas	84.9	99.8	142.7	168.4	18.0%
Sewage sludge digestion	87.1	86.9	92.6	92.7	0.1%
Municipal Solid Waste combustion	86.8	86.8	115.0	115.0	0.0%
Other - farm waste etc.	45.6	45.5	45.5	45.6	0.2%
Total biofuels	304.4	319.0	395.8	421.7	6.5%
Total	**412.3**	**448.4**	**559.6**	**612.9**	**9.5%**

+

5.1.2 Non Fossil Fuel Obligation (NFFO)

Most of the renewable generation was under the Non Fossil Fuel Obligation (NFFO) arrangements. At the end of 1997, there were 197 NFFO schemes operating in England and Wales, and 10 in Scotland, with a total capacity of 492 MWe DNC, providing 85% of the renewable electricity. Table 8 gives a summary; landfill gas and waste make up more than half the commissioned capacity, with identifiable 'pure' renewables (small hydro and wind) making up about a quarter. Further details of the NFFO schemes may be found in [12] and [13].

Table 8 Renewables Obligation Status Summary

Technology	Contracted projects		Commissioned projects as at 30/09/98	
	No	Capacity (MW DNC)	No	Capacity (MW DNC)
Biomass	31	243	5	64
Hydro	141	91	50	35
Landfill Gas	315	673	99	189
Municipal and Industrial Waste	88	1376	13	180
Sewage Gas	31	34	24	25
Wind	274	1076	57	137
Totals	**880**	**3493**	**248**	**630**

The new NFFO, NFFO-5, was announced on 24 September 1998. This comprises 261 projects which total 1177MW Declared Net Capacity (DNC), this is the largest Order since the NFFO began in 1990. It is also the cheapest, with an average price of power of only 2.71p/kWh, compared to the average pool price of 2.67p/kWh. The breakdown of projects with contract prices is shown in Table 9. To put the Order into context, 1177MW DNC is enough electricity to meet the average requirements of 1.4 million homes. Sizes of schemes vary widely, from an average of 0.41MW DNC for small-scale hydro up to 18.91 MW DNC for energy from waste. Both types of energy from waste (with and without CHP) come in at an average contract price below the average pool price.

Table 9. Summary of NFFO 5 projects.

Technology	Number of projects	Capacity (MW DNC)	Average capacity (MW DNC)	Lowest price (p/kWh)	Average price (p/kWh)	Highest price (p/kWh)
Landfill gas	141	314	2.23	2.59	2.73	2.90
Energy from waste	22	416	18.91	2.39	2.43	2.49
Energy from waste using CHP	7	70	10.00	2.34	2.63	2.90
Small-scale hydro	22	9	0.41	3.85	4.08	4.35
Wind > 0.995 MW DNC	33	340	10.30	2.43	2.88	3.10
Wind <= 0.995 MW DNC	36	28	0.78	3.40	4.18	4.60
TOTAL	**261**	**1177**	**4.51**	-	**2.71**	-

5.1.3 Combined heat and power

Combined Heat and Power (CHP) plant produces power, usually electricity, and useful heat. Only CHP plant producing electricity are considered here. In 1997 there was a total of 1,360 sites with an installed capacity of 3,732 MWe which produced 19,465 GWh of electricity and 62,677 GWh of heat. The electricity produced accounted for about 6% of total UK generation. Throughout this section, figures represent overall electricity capacity and production of CHP plant without a breakdown between use on site and export to the distribution network. Such information would be very difficult to obtain, and in any case electricity used on site is displacing what would otherwise have to be imported. Table 10 gives a summary of CHP plant over the last four years, from [12]. Since 1988 capacity has grown at an average rate of 8.5% per annum, but from 1996 to 1997 it grew by only 5%, partly due to uncertainty over fuel prices and interest rates.

Table 10. Summary of CHP plant.

	1994	1995	1996	1997	Increase 1996-7
Number of sites	1,167	1,277	1,336	1,360	1.8%
Electrical capacity MWe	3,141	3,487	3,562	3,732	4.8%
Electricity generation GWh	12,152	17,761	19,081	19,465	2.0%

Figure 4 shows the growth in capacity from 1994 to 1997, and compares this with the official target of 5,000MWe by the year 2000, and an unofficial target of 10,000MWe by 2010. This is the bottom of the range 10,000-17,000MWe estimated by ETSU in early 1997 as the potential for CHP, depending on the investment criteria used. While the 2000 target seems likely to be met, there would have to be 7.2% compound growth to achieve the 2010 target from the year 2000. This is a similar growth rate to the historical rate, but ambitious given that 79% of current capacity is from sites over 10MWe, where the potential for growth is probably limited. This implies a much higher growth rate needed for smaller scale CHP. If a lower growth rate of 4.8% is used, i.e. a value nearer to current levels of growth, then this would give a projected

CHP capacity of 8,000MWe by the year 2000. This may still be optimistic as the potential for growth in the larger (over 10MWe) sites is limited.

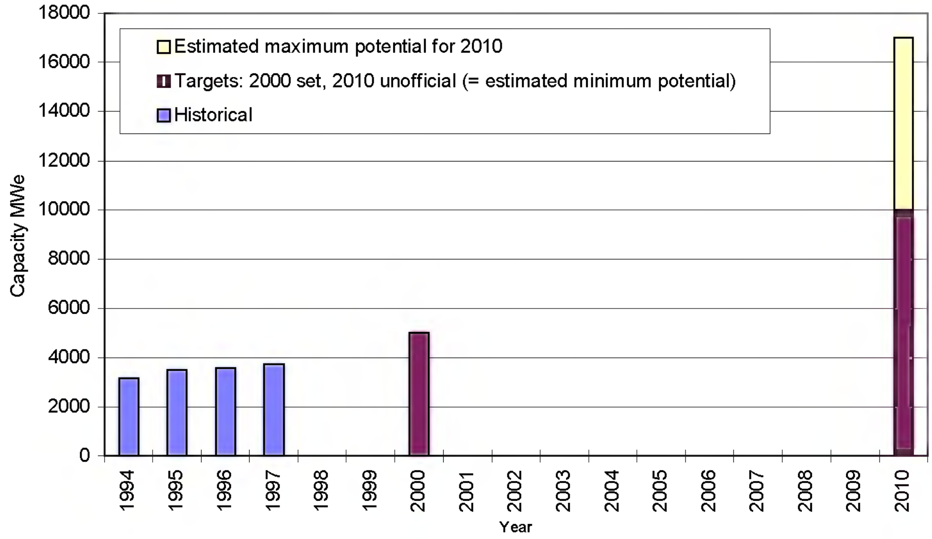


Figure 4. Historical CHP electrical capacity, targets and projections.

A breakdown of plant by number and capacity is given in Table 11, from [12].

Table 11. CHP installation by capacity size ranges in 1997.

Size range (electrical)	Number	Share of sites	Total capacity MWe	Share of capacity (%)
Less than 100kWe	677	49.8%	37.6	1.0%
100kWe - 999kWe	454	34.4%	116.8	3.1%
1MWe - 9.9MWe	150	11.0%	611.8	16.4%
Greater than 10MWe	65	4.8%	2,965.7	79.5%
Total	1360	100.0%	3731.9	100.0%

Clearly numbers are dominated by small plant, while capacity is dominated by large plant; this is illustrated in Figure 5 which shows numbers and capacity by size range. Sites below 100kWe form half the number, but only contribute 1% of capacity, while the 5% by number of largest sites contribute 80% of the capacity.

This has implications for embedded generation; a few large sites should be easier to deal with than many small sites in terms of connection, but large sites will have a greater impact on the local network. However, as mentioned previously, the scope for growth of capacity in large plant is probably limited. Therefore, if a high rate of growth in CHP is achieved as the government would like, this is likely to come mainly from the small to medium sectors of the market. Some of the very small sites (internal combustion engines) may not export at all to the network, but there is no information on this. It is certain from Table 11 that the vast majority of CHP *capacity* will be able to export.

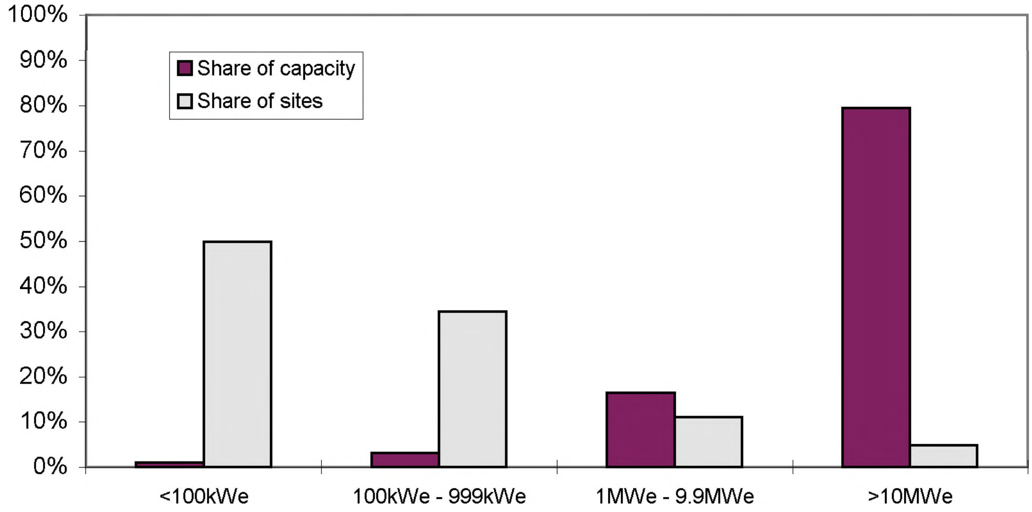


Figure 5. Share of CHP sites and capacity as a percentage of the total by size of site.

Perhaps surprisingly, natural gas accounts for only 53% of CHP fuel input, as shown in Figure 6, with most of the rest from oil, coal and gases produced as industrial by-products. This reflects the fact that most of the fuel is consumed by large CHP plant, which often use industrial by-products or coal. Renewable fuel sources only accounted for 1,761 GWh out of a total of 112,628, or 1.56%.

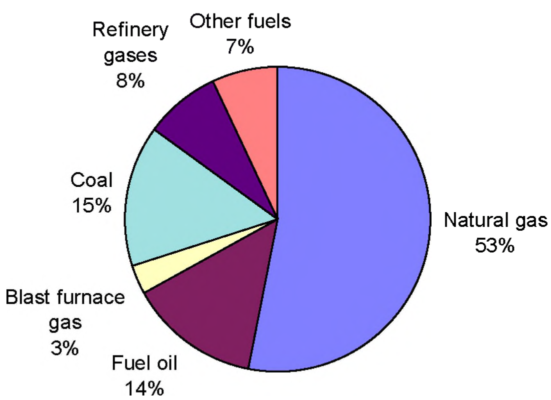


Figure 6. Fuels used in CHP plant in the UK, 1997.

5.1.4 CHP in buildings

The use of CHP in buildings represents an important area for embedded generation, because it is likely to grow more quickly than other sectors, and is more deeply embedded than large plant with established network connections. The total installed capacity in 1997 was 280 MW, with 98% of schemes based on spark ignition reciprocating engines fuelled with natural gas. In terms of capacity the largest sectors are health and residential buildings with 31% and 22% of electrical capacity respectively. In terms of the number of sites the market is dominated by three sectors: health with 23% of sites; hotels 27%; and leisure with 33%. Much of the electricity generated is likely to be used internally.

Another type of technology which may have a large impact in the future is micro CHP based on Internal Combustion (IC) engines, Stirling engines and fuel cells. These are being developed in several countries to replace domestic gas boilers. Heat-led micro CHP with electrical outputs of 0.5 to 5 kW has potential to revolutionise electricity production for houses and other small buildings. The technology is currently at stage of prototypes and field trials. With a market penetration of 35%, from statistics for housing stock, gas consumption and gas boiler sales gives the potential annual sales for 3 kWe/9 kWt units of 29,000 and 1 kWe/6 kWt units of 100,000. This would lead to growth in the UK of up to 200 MW per annum over the next 15-20 years with the potential for around 2 million units to be installed by 2015 with a combined capacity approaching 3 Gigawatt electric (GWe) [14]. A detailed analysis of the potential for micro CHP is given in [14]. Load patterns from individual dwellings are very 'spiky', with a base load typically below 1 kW but peak loads of several kilowatts. This makes it impossible to run micro CHP in a load-led mode. Therefore micro CHP units could export a significant proportion of their output. However, it may be more economic to avoid exporting and convert any surplus electricity back into heat. In this case the effect on the network would be to reduce consumption without putting power back into the network.

5.2 Targets for the future

5.2.1 Greenhouse gas emissions

5.2.1.1 European Union

Following the Kyoto Summit in December 1997, the world's industrialised nations committed themselves to a collective cut in greenhouse gas emissions of 5.2% on 1990 levels by 2008-2010, calculated as an average over those five years. Targets among individual countries range from much larger decreases in some, to increases in others. Compared to what would be expected without controls, the target is estimated by the United Nations (UN) to be equivalent to a 30% cut.

5.2.1.2 United Kingdom

Under the agreement, the European Union (EU) is committed to an overall reduction of 8%. However, prior to Kyoto, the UK Government was committed to a unilateral 20% cut (relative to 1990 levels) by 2010 in carbon dioxide emissions pledged in their manifesto. Carbon dioxide is the main greenhouse gas. So far, how these targets can be achieved is not clear; the House of Commons Environmental Audit committee has described the 20% CO_2 target as 'very challenging'.

5.2.2 Renewable generation

5.2.2.1 European Union

A European Commission White Paper was adopted in November 1997 setting out a strategy and action plan to achieve a doubling of the EU's share of total *energy* supply from 6% currently, to 12% by 2010. Action to achieve this is expected to be mainly at Member State level. Specific targets include:

- Introduce 500000 new photovoltaic systems in the EU
- Install 10000MWe of large wind farms
- Develop 10000MWth of biomass installations
- Integrate renewable energies in 100 communities

There is also an interim EU policy target of 8% share of renewable energy by 2005.

5.2.2.2 United Kingdom

The Minister for Science, Energy and Industry, John Battle MP, has undertaken an appraisal of what would be needed to provide 10% of UK electricity from renewables by 2010. Whilst not an official target, this is clearly a good indication of the sort of figure which might be set as a target, although it is more than 10 times the current level, and compares with the 3% target supported by the previous government's policies for developing 1500MW DNC of new renewable generating capacity by 2000 . To achieve 10% renewable generation would require an additional 2500-3500MW DNC to be commissioned within the next 10 years, in a market which already has excess generating capacity.

The implications of 10% of UK power from renewables by 2010 relates to the total UK electricity generating capacity of about 60 GW. Therefore 10% can be taken as about 6 GW.

Existing large-scale hydro and all contracted NFFO/SRO/NI-NFFO schemes (up to NFFO 4) combined would account for about 2.5GW. A further 3-4GW DNC would therefore be needed to reach the 10% mark. For various reasons, projects could be expected to be around 5MW on average (predominantly from energy-from-waste and onshore wind, but offshore wind and biomass would also be expected to play a part), and we would thus still need a further 800 schemes. So, in total, up to 2000 projects may be expected to enter the planning process in the next ten years.

5.2.3 Combined Heat and Power

The current UK target for Combined Heat and Power (CHP) is to achieve 5000MWe by the year 2000, and this target is likely to be met or nearly met. Note that much of this capacity will be used on site, so not exported to the network. Plant will normally be run when there is a demand for heat, which usually coincides with a demand for electricity.

5.3 General projections for embedded generation

The three most important sources of information on future levels of embedded new and renewable energy in the UK are, in chronological order, [15], [16] and [17]. A new report by ETSU on renewable energy is expected shortly. There are two major difficulties in analysing projections:

- Rapid technical, economic and political change which quickly make projections outdated

- Many permutations of economic growth, fuel prices and environmental influences are used for scenarios

Other reports have looked at the *potential* for a given technology - while these are useful exercises, they are not intended to be realistic scenarios, such as the calculation that if every south-facing wall and roof in the UK was clad in photovoltaics, they could generate 208 Terrawatt hour (TWh), or 68% of the total UK electricity used in Britain in 1995 [18]. More realistically, they can be used to examine the consequences of a given fraction of the potential being realised.

Within the electricity industry, the pace of change has been exceptionally fast, with even the conventional generation mix changing dramatically since these reports were written, having knock-on effects on the economics of embedded generation.

Projections have been grouped by source, rather than by technology, because each set of projections was made at a certain time and with a certain set of assumptions, time frames etc.

5.3.1 An assessment of renewable energy for the UK, 1994

ETSU carried out a major study on the potential for renewable energy in the UK which was published in 1994 [15]. Although somewhat out of date, it is the most detailed assessment for the UK currently available. Its projections are based on Maximum Practicable Resource (MPR); this is the maximum economic exploitation of a given resource by a mature technology (assuming a given price per kWh) within regulatory, sociological and environmental constraints. Many of the constraints are highly subjective, since the extent of existing schemes was even more limited at the time of the study than it is now.

Figure 7 to 10 give the MPR supply curves for electricity generation from different renewable resources for 2005 and 2025 at discount rates of 8% and 15%. All costs are at 1992 prices. Note that the y-axis scales on the 2025 graphs are roughly three times greater. As technologies develop their costs are expected to fall while their ability to exploit their resource increases. These are the principal reasons why the MPR is expected to be cheaper (shown by technologies becoming viable at a lower price per kWh) and greater (shown by wider bands at the highest price per kWh). These plots should be read by picking an economic price per kWh on the x-axis and reading off the proportions of each generation type on a vertical line above it. Proportions on the right hand side only apply when the economic generation cost reaches 10p/kWh. Note that in all cases, if economic generation costs for conventional power remain below about 2.5p/kWh (1992 prices), then renewable energy will only make a small contribution under all scenarios unless heavily subsidised.

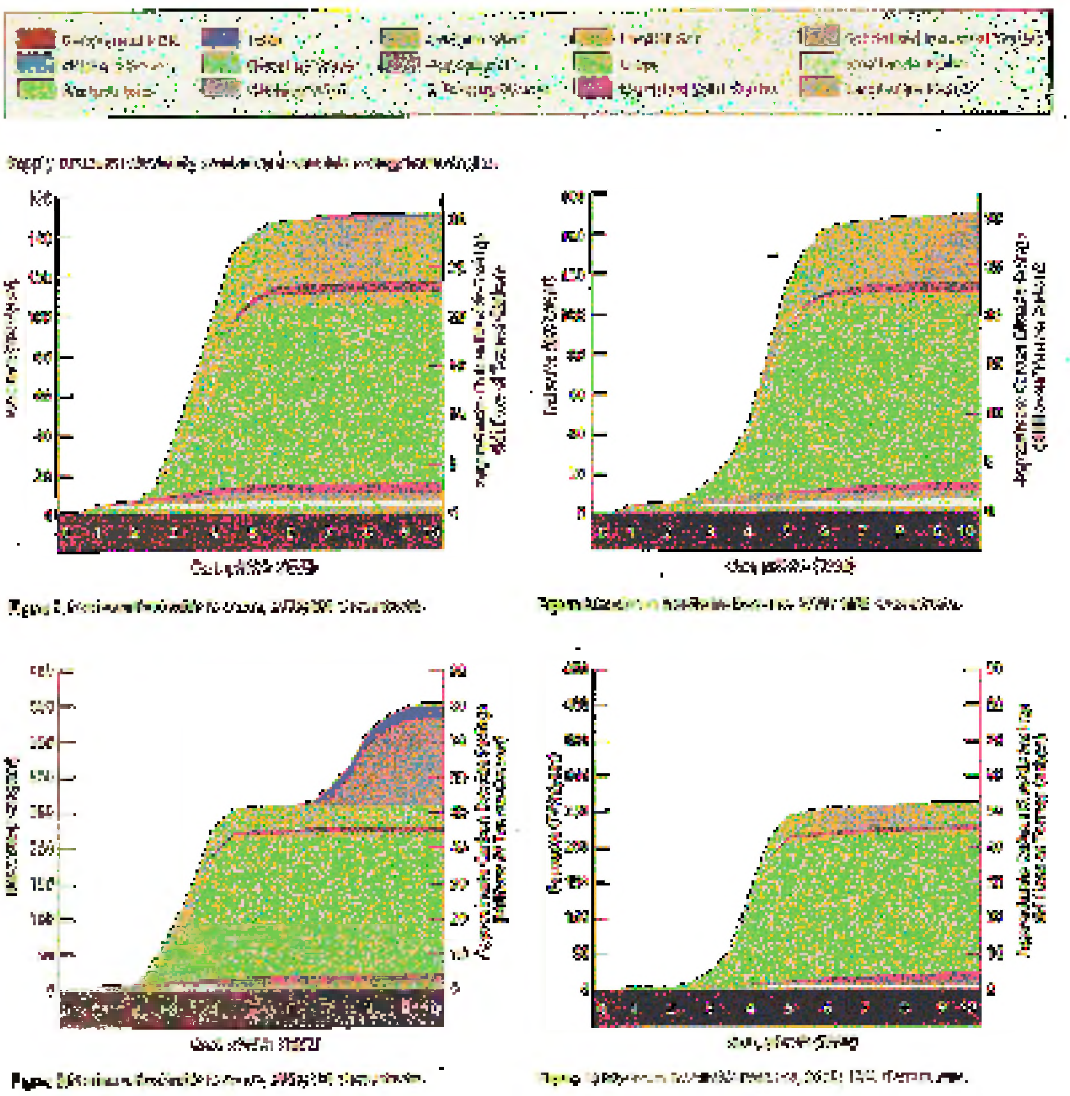


Figure 7 to 10. Maximum Practicable Resource of renewables under various scenarios.

Assuming that the 8% discount rate is the more likely, by 2005 (Figure 7) the MPR of renewable electricity has a maximum of about 147 TWh/year, depending on costs. This equates to about 43% of the 345 TWh of generation in 1997, though overall demand by that time would probably also have increased. Generation is dominated by crops (around 60%) and onshore wind (around 22%) at the higher prices. Most technologies have reached full viability at a price of about 5.5p/kWh, with the exception of tidal which requires about 7p/kWh.

Moving ahead to 2025 at the same discount rate (Figure 9), if generation costs are above 7p/kWh then tidal power starts to make a much more significant contribution to the MPR, up to about 30% of the total at the highest price, and offshore wind becomes the third largest contributor after crops and onshore wind at the high price end, contributing about 4%. Photovoltaics begin to make a contribution which is just about discernible when the price exceeds 9.5p/kWh. At the higher discount rates, which favour schemes with lower capital cost, only hydro, waste products, crops and onshore wind appear on the graphs. Overall, the graphs show the importance of generation costs in determining the potential renewable contribution, and the dominance of crops, waste and onshore wind under all scenarios.

However, the MPR supply curves as shown in Figures 7 to 10 are not predictions of what is likely to occur, "but realistic assessments of what could be supplied if things go well for renewables and appropriate RD&D is undertaken. The supply curves are the input data to the energy systems modelling exercise, which addresses energy demand as well as energy supply" [15]. The report goes on to make predictions of the uptake of renewables under various scenarios of fuel price and environmental concern, using the MARket ALlocation (MARKAL) energy systems model developed by the International Energy Agency (IEA). This is a linear programming model that meets defined useful energy demands at least cost. As such it does not necessarily predict what will happen in the future, but instead defines the most cost-effective way of satisfying the UK's energy requirements. It is the premier model for analysing the prospects for new and renewable energy technologies and the environmental implications of their use. These predictions are considerably less than the MPR values plotted in Figure 7 to 10. They are summarised, for the year 2010, in Table 12 [15].

Table 12. UK electricity generation and contribution from renewables under various scenarios in the year 2010.

Scenario	Total generation TWh/year	Renewable generation TWh/year	Renewable generation %
HOP - High oil price, low coal price	290	12	4
CSS - Composite scenario from 1990 views on future prices	290	6	2
LOP - Low oil and gas prices	280	11	4
HECA - 'Green' future of carbon taxes, heightened environmental concern and run-down of nuclear plant.	250	108	43
HECB - 'Green' future of heightened environmental concern but with new nuclear generation.	250	65	26
SS - Shifting sands, as 1 but with oil price shocks superimposed.	290	12	4

These may be compared with the predictions for renewables in Energy Paper 65 [16]. This reference concentrates on predicting energy demand and contains little about renewables, but it does include predictions for the proportion of total generation under different scenarios. These scenarios are not equivalent to those in Table 12, but instead are the six permutations of low, central and high GDP growth combined with low and high fuel prices, given in Table 13.

Table 13: Economic scenarios used in Energy Paper 65 and referred to here.

Scenario	Abbreviation
Low GDP growth - Low fuel prices	L-L
Low GDP growth - High fuel prices	L-H
Central GDP growth - Low fuel prices	C-L
Central GDP growth - High fuel prices	C-H
High GDP growth - Low fuel prices	H-L
High GDP growth - High fuel prices	H-H

These scenarios do not include the consciously 'green' scenarios HECA and HECB which make the large impacts shown in Table 12. Energy generation data in Energy Paper 65 are given in terms of GW capacity, not TWh generated. Therefore they cannot be compared directly with Table 12, although the percentages should be comparable assuming load factors for renewables (in DNC terms) and conventional generation are similar. Under these scenarios, the contribution of renewables to electrical generation capacity in 2010 ranges from 5% to 7%.

A more recent set of predictions is made in another ETSU report[17], again using the MARKAL model. Yet another set of scenarios were used, based on the Energy Paper 65 combinations of growth and fuel price (Table 13), but with other permutations including: constraining total UK carbon emissions to 10% and 20% cuts by 2010 compared to 1990 levels; the option of no new nuclear power; low and high fuel prices; upgrades to Scottish/Northern Ireland interconnectors; and discount rates of 8% and 15%. The base scenarios were for different economic scenarios, but assuming an 8% discount rate and interconnector upgrade with no special environmental constraints. Additional scenarios were considered as follows, which combine features from HECA, HECB, and a carbon constraint with C-H:

C-HA Central high, with no new nuclear, no closure of existing nuclear plant, and 20% carbon constraint from 2005.

C-HB Central high, with new nuclear allowed, no closure of existing nuclear plant, and 20% carbon constraint from 2005.

Data presented here are from the updated MARKAL runs for all scenarios. Table 14 shows the predicted growth in total renewables under the base and 'environmental' scenarios up to 2020[17].

Table 14. Percentage contribution of renewables to electricity generation to 2020.

Type	Scenario	1990	1995	2000	2005	**2010**	2015	2020	2025
Base	CSS	2.18	2.55	3.44	3.45	**3.80**	3.70	6.59	6.47
Base	LOP	2.18	2.62	3.30	3.23	**3.31**	3.24	3.24	3.23
Base	HOP	2.18	2.61	3.31	3.34	**3.88**	3.73	3.66	3.68
Base	C-L	2.12	2.58	3.41	3.34	**3.23**	3.41	3.30	3.31
Base	C-H	2.12	2.64	3.47	3.42	**3.67**	4.57	4.42	5.93
Base	L-H	2.12	2.66	3.52	3.52	**3.50**	4.84	4.72	6.42
Base	H-L	2.12	2.52	3.32	3.22	**3.35**	3.23	3.13	3.10
Env	HECA	2.18	4.98	18.96	31.03	**51.38**	64.25	64.35	65.51
Env	HECB	2.18	4.98	18.96	27.02	**26.08**	25.11	24.31	16.52
Env	C-HA	2.12	2.64	2.51	6.99	**11.52**	27.81	57.78	67.34
Env	C-HB	2.12	2.64	2.51	6.99	**7.98**	7.99	9.43	10.09

The base scenarios are shown graphically in Figure 11, and the environmental scenarios in Figure 12. Note that the scales on these differ by a factor of 10. The scenario giving the lowest proportion of renewables is, not surprisingly, high GDP growth with low fuel prices (H-L). All the base scenarios are similar up to 2010, after which some fall slightly while those with high fuel prices rise sharply, fuel price being the driving factor. All the renewable energy in these scenarios comes from waste, hydro and wind.

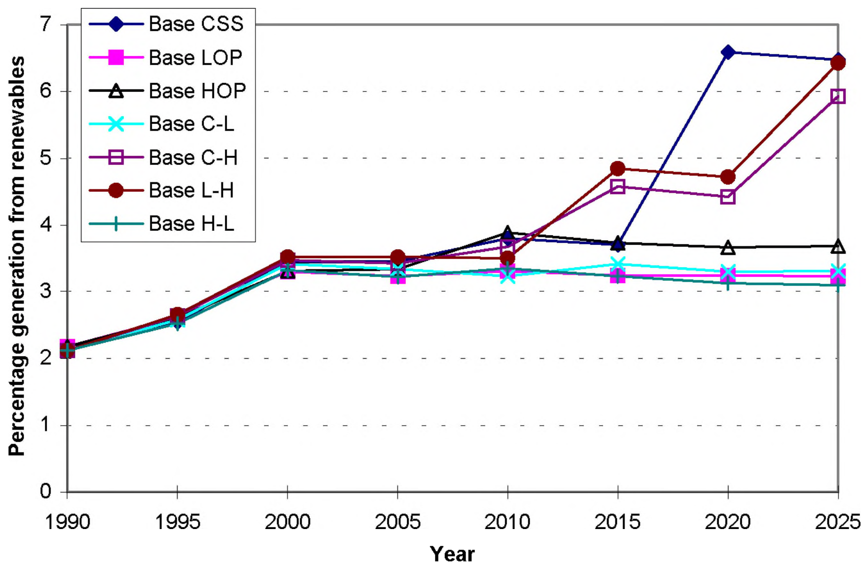


Figure 11. Percentage renewable generation in UK for base scenarios, using data from [17].

In 2010 the highest renewables scenario is HECA, by a factor of two, but by 2025 this is just overtaken by C-HA. The effect of no new nuclear plant for the -A scenarios is evident in the bifurcation of the two pairs of scenarios HECA/B and C-HA/B after 2000 and 2005 respectively. The HEC scenarios have a carbon tax applied in 1995 [sic] which increases in 2000. C-HA/B have carbon constraint from 2005, which has the effect of roughly doubling the renewables contribution compared to the base scenario C-H, in 2005. Nuclear policy results in the -A and -B scenarios ending up quite similar by 2025. As well as waste, hydro and wind, energy crops are important, with a very small contribution from wave energy, by 2025.

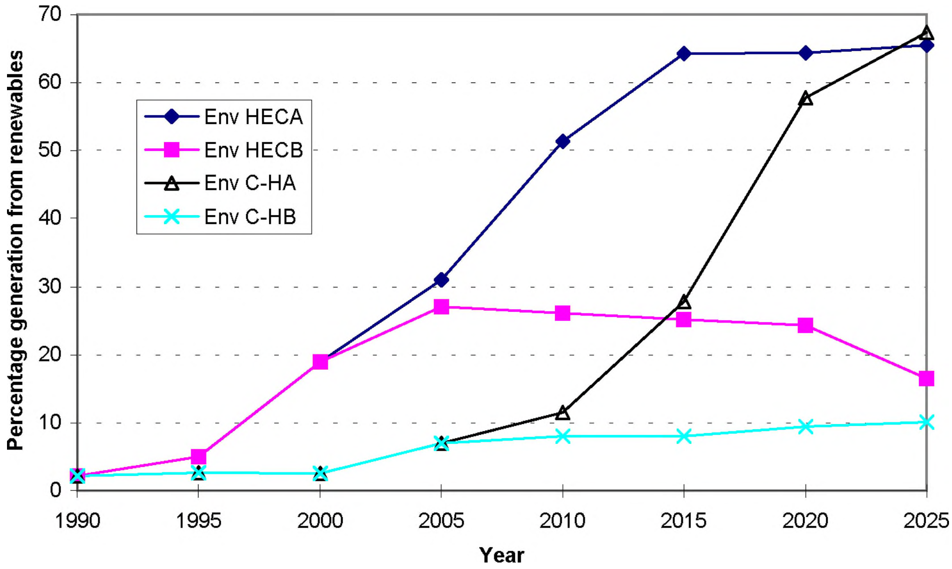


Figure 12. Percentage renewable generation in UK for environmental scenarios, using data from [17].

The breakdown of the renewable contribution under these various scenarios is given in Table 15 for the year 2010, and graphed in Figure 13. Another scenario has been added, C-L20, which is the closest to the current 'best guess' scenario based on 1998 information. (This scenario was included in an appendix to [17] but not presented in the main report, and actual percentages renewable contribution were not given.) It can be seen that only with a carbon constraint (C-HA, C-HB and C-L20) do the total new renewables exceed existing hydro capacity, with the main contributions coming from onshore wind and waste. Photovoltaics and marine power (wave, tidal and offshore wind) are too small even to appear in the tables at this date. The 'best guess' scenario has the second-highest amount of renewable generation after C-HA, which includes high fuel prices so now seems an unlikely scenario.

Table 15. Contributions of different renewable technologies to electricity generation in 2010 under various scenarios.

Technology	C-L	C-H	H-L	L-H	C-HA	C-HB*	C-L20=
Existing hydro	6.18	6.18	6.18	6.18	6.18	6.18	6.18
New hydro	0.03	0.16	0.34	0.16	0.82	0.34	0.34
Onshore wind	0.52	0.52	0.52	0.52	13.31	4.19	8.36
Municipal and industrial waste	1.05	3.51	1.05	1.05	7.76	8.40	8.14
Agricultural and forestry waste	0.22	0.40	0.40	0.40	4.94	0.40	1.51
Energy crops	0.00	0.00	0.00	0.00	1.86	0.00	0.00
TOTAL	8.00	10.77	8.49	8.31	34.87	19.51	24.53

* as C-HB except for 10% carbon constraint instead of 20%, from 2005
=central GDP, low fuel price with 20% carbon constrain from 2005

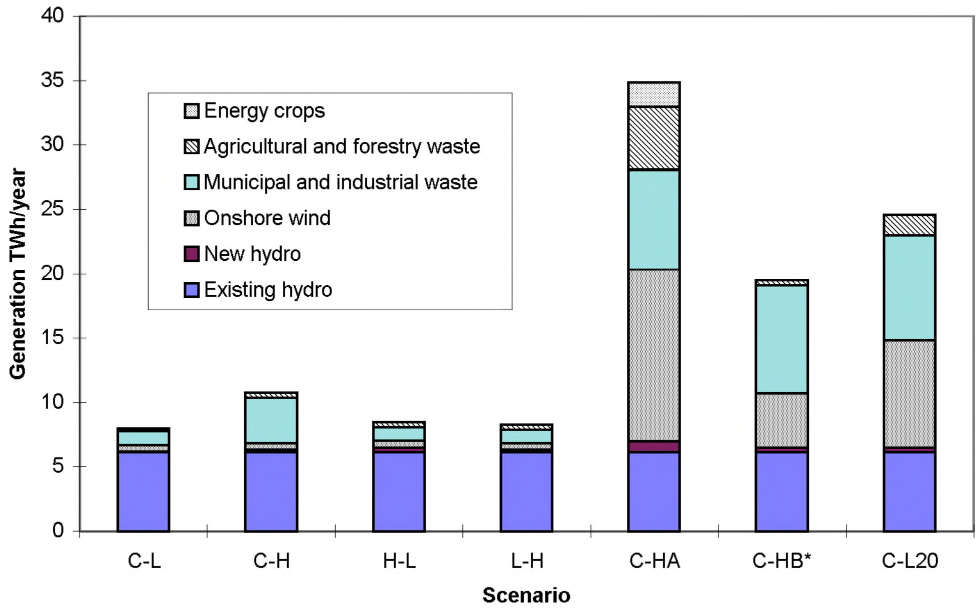


Figure 13. Breakdown of renewable electricity supply for 2010 under various scenarios.

* as C-HB except for 10% carbon constraint instead of 20%, from 2005

5.3.2 Conclusions on future renewable generation

The report makes the following conclusions:

- From 2015, some renewable energy technologies are forecast to be commercially viable on cost grounds alone. However, NFFO-5 demonstrates that renewable energy technologies are viable now, with an average price of power of only 2.71p/kWh, compared to the average pool price of 2.67p/kWh. With landfill gas, energy from waste, energy from waste using CHP and larger scale wind schemes having the lowest price of power below the average pool price.
- Technologies which are viable from 2015 include; landfill gas, energy crop gasification, onshore wind, and agricultural and forestry waste gasification. Of

these it is landfill gas which is the most robust under all analyses and which is used to its maximum resource in all scenarios from 2020.

- The level of onshore wind deployment forecast into the future is sensitive to discount rate and to assumptions about interconnector upgrades. If a 15% discount rate is used, or it is assumed that upgrades to the Scottish/Northern Irish interconnectors do not take place, then electricity generation by onshore wind turbines is substantially reduced.
- If carbon abatement is required, the Electricity Supply Industry (ESI) is the most cost-effective sector in which to achieve it. Renewable technologies play a large part in achieving carbon reductions cost-effectively, along with fuel switching into natural gas and nuclear expansion if allowed. If the fuel mix in the ESI in the future is largely based on natural gas and no nuclear expansion takes place, then renewable energy technologies would represent the most cost-effective way of reducing carbon (and as a result other gaseous) emissions.
- Technologies chosen as the most cost-effective for further reductions in carbon emissions include; energy crop gasification, onshore wind, and agricultural and forestry waste gasification.

With the benefit of hindsight, it is easy to spot where predictions fail to agree with what has already happened. Although all scenarios predicted renewables would be contributing over 2.5% of generation in 1995 and rising (Table 14), the actual figure for 1997 was only 2.1%.

Table 16 compares actual spot market fuel prices on 11 September 1998 (1998 money) with the predicted prices used in the scenarios (1990 money). In 1990 money, the current low prices would be even less; we are currently in a 'Very Low Fuel Price' scenario. To reach a 'High' scenario prices would have to more than double in less than two years, which seems very unlikely. Given that renewable penetration is largely driven by price in the conventional scenarios, this makes the economics of renewable generation considerably worse.

Table 16. Actual (September 1998) compared with high and low scenario fuel prices for oil and gas.

	Oil $/barrel			Gas p/Therm		
Date	High	Low	Actual	High	Low	Actual
1995	20.0	15.0	-	20.0	16.0	-
Sept 1998	-	-	13.0	-	-	12.5
2000	25.0	15.0	-	26.0	20.0	-

On the nuclear side, the application for Sizewell C nuclear power station was recently rejected and an expansion of nuclear power seems very unlikely within the next few years, though it is also very unlikely that existing plant would be shut down prematurely (as it is in scenario HECA).

However, following the Kyoto agreement, the 'carbon constraint' is already beginning to happen, earlier than 2005 as assumed in the C-HA/B scenarios, with some sort of carbon or fuel tax almost inevitable in the near future. Electricity, because of its centralised generation and current high level of CO_2 contribution, is likely to be strongly targeted both in terms of end use and generation mix.

Future economic growth remains as uncertain as ever, and is always likely to be cyclical. Achievement of sustained, low inflation growth has been knocked off course by the Asian and Russian crises. Most would predict more stable growth than in past decades, with a high rate of growth unlikely over a long period. Taking these together, the nearest 'best guess' scenario would appear to be C-L20 described in Table 15 which is:

- Central GDP growth
- Low fuel price
- 20% carbon constraint with no new nuclear

Under this scenario the predicted contribution for renewable generation is 24.53 TWh/year, i.e. 8% of generation compared to the current level of 2.1%. The majority of this capacity comprises: existing hydro (6.18 TWh/year), onshore wind (8.36 TWh/year) and municipal and industrial waste (8.14 TWh/year).

5.4 Further information

Previous sections have looked at general projections of renewable energy from econometric models. This section considers other sources of information on specific issues and technologies, much of which is more up to date than the model projections.

The "best guess" scenario outlined in the previous section may be conservative if the predications for some of the renewables prove to be accurate. In particular if a new technology band for offshore wind is included under future NFFO arrangements the large potential for offshore wind could be realised. The estimated level for 2010 is 14.5 TWh/year which is considerably more than the onshore wind in the "best guess" scenario this would increase the renewable contribution to 13.5%.

Energy from farm crops and waste has large potential, but little of this has so far been realised. However, with competitive costs for poultry waste and farm biogas, combined with other environmental benefits, it seems likely that these areas could expand considerably.

5.4.1 Future support for renewables

As the future of NFFO is under review, a number of energy policy researchers have considered the options for government support for renewables.

The Council for the Protection of Rural England (CPRE) has produced a report[13] looking in detail at policy options on renewable energy. It was written by Dr Catherine Mitchell of the Science Research Policy Unit at Sussex University. The CPRE is concerned about the potential damage to the landscape of more renewable projects such as wind and hydro schemes. The main push for renewables is to reduce CO_2 emissions - an environmental protection aim. Dr Mitchell argues that "the deployment of renewables should therefore occur as part of a wider sustainable development policy".

The NFFO process has clearly been successful in reducing prices and subsidies per kWh, supporting a number of near-market technologies and developing professional industries for those technologies, the report argues. But competitive bidding has been less successful in supporting technologies like hydro or energy crops. The limited number of technologies receiving funding has concentrated development in certain areas, such as wind power in the South West and Wales. A preferable mechanism would be one which combines the most successful attributes of competitive bidding with an approach using 'standard payments'. In this method, used on the continent, a standard payment per kWh is publicised before the application process begins. This would enable potential developers to assess better the viability of a project before committing to it. A combined approach could then be applied to each technology, appropriate to its current stage of development.

In addition to the existing technology-specific categories, there should also be an 'open technology' band. This would act as a short term support measure between the NFFO process and the development of the green electricity market. It would have a pre-established fixed price pegged to the minimum value of embedded generation. Premium payment technology bands should be set up, argues the report, to promote the more expensive technologies while in their early development stages. Such changes could encourage diversity in renewable energy and reduce the environmental impacts that can occur through a purely price-based approach.

As the domestic market opens up to competition, Fouquet[19] discusses the interactions between the behaviour of domestic consumers, and the market for 'green' electricity sold at a premium. He concludes that the take-up of green power will be driven by renewable generation capacity, and information which consumers have on the environmental effects of different types of electricity generation. He believes that development of renewables will depend critically on initial consumer demand: "Too little demand may smother future investment in R and D and generation capacity. Too much demand may drive up prices, encouraging customers to believe in the benefits of free riding from buying green electricity [buying from cheaper conventional sources while hoping to benefit environmentally from other customers paying a premium for green power] and, therefore, even with lower prices as more generation capacity enters the market, inelastic beliefs will mean few customers will want to buy renewable electricity in the future". He advocates continued financial support of renewables through the extension of NFFO, combined with appropriate information provision to consumers. In this early stage of the competitive market, neither of Fouquet's somewhat pessimistic scenarios appears to be happening, and it seems likely that the market for green electricity will 'find its level' as consumers gradually switch suppliers.

5.4.2 Photovoltaics and photoconversion

Despite a lot of public interest, photovoltaics (PV) currently make an insignificant contribution to renewable energy in the UK. Economic photovoltaic installations tend to be in niche markets, such as supplying small amounts of electricity to remote sites with no mains power, particularly in the developing world. Installations have a long lifetime and low maintenance, and can be incorporated into the cladding on a building with costs offset by the savings in conventional cladding. Because of the intermittent nature of solar energy, they usually need to be connected to a battery system or to the electricity network[20].

The number of grid-connected PV in the 1-5 kW range has increased through the 'PV on roof tops and facades' programmes operating in several European countries, and the number of multi-hundred kW and MW sized plants is increasing. Lifetime costs of roof-top systems are of the order of 0.35-0.90 ECU/kWh for western Europe, and 0.25-0.60 ECU/kWh for southern Europe, and around 0.35 ECU/kWh for central power stations in southern Europe. These compare with customer tariffs in the range 0.15-0.19 ECU/kWh (1996 prices).

Module costs are expected to fall from more than 3 ECU/Wp to less than 1.5 ECU/Wp in the medium term. The break-even point for roof-integrated applications in Europe is about 1.5-1.75 ECU/Wp at the module level - modules account for about 50% of the cost of grid-connected systems. Therefore grid-connected PV systems could be competitive around 2005, at least in areas of Europe with high sunshine. It is estimated that 50% of annual electricity consumption could be provided by a PV system adding only 2.5% to the overall building cost. However, this would only apply to new housing which would make up a tiny proportion of the total stock.

Projections from [20] for 2010 are for an installed European capacity of more than 5GWp. It is not stated whether this is maximum capacity or DNC. Given that the UK is a northern country with relatively low sunshine, only a small part of this - say 10% - is likely to be in the UK. A UK capacity of 0.5 GWp compares with an average electrical power consumption in 1997 of 39 GW - that is, PV would only generate about 1% of current average load under favourable conditions.

5.4.3 Wind power

The most up-to-date projections on wind energy have been produced by the British Wind Energy Association (BWEA) as an addendum to their policy statement [21], replacing the projections in the original document. Table 17 reproduces these. It is interesting to note how the projections have changed since 1996; the original table did not distinguish between on and offshore, but relevant data are shown in the last column. Total generation, generation as a percentage of UK demand, and new turbine size projected for 2010 are all considerably higher. This partly reflects the rapid pace of technical development. In Denmark, for example, the efficiency of wind turbines, measured in output per square metre swept by their rotors, increased by 5% annually from 1981 to 1996, or in other words efficiency more than doubled.

Table 17. Current projections for onshore and offshore UK wind energy to 2010, with 1996 projections for 2010 in last column.

	1997	2000	2005	2010	*2010[1996]*
Onshore wind energy					
Onshore capacity (MW installed)	318	650	1810	3710	-
Average size of new turbines (MW)	0.6	1.0	1.5	1.5	*1.2*
Cumulative number of turbines	719	1144	2030	3297	-
Generation onshore (TWh)	0.8	1.7	4.8	9.7	-
Offshore wind energy					
Offshore capacity (MW installed)	0	40	2400	5000	-
Generation offshore (TWh)	0.0	0.1	6.9	14.5	-
Total generation (TWh)	0.8	1.8	11.7	24.2	*13.1*
Forecast UK electricity demand (TWh)	333	346	370	393	-
Wind as % total UK supply (%)	0.25	0.53	3.16	6.16	*4.19*

5.4.3.1 Wind energy prices

The contract price range for NFFO4 was 3.11-3.80p, while the contract prices under Scottish Renewables Obligation (SRO) averaged 2.78p, comparable with conventional generation. Once savings in distribution losses and costs resulting from the generation being embedded have been taken into account, the costs become even more attractive. Also, unlike some renewables such as solar, wind generation roughly follows the UK demand pattern with highest output in the winter and lowest output in the summer. However, most wind farms are in hilly regions remote from large centres of population.

A new technology band for offshore wind is expected under future NFFO arrangements. The DTI and Crown Estates are consulting the BWEA about the detailed arrangements[22]. Energy minister John Battle launched a consultative document on opening up NFFO in future to offshore wind energy at the British Wind Energy Association's conference in Cardiff on 2 September 1998, saying that the DTI hoped to see five or six projects initially. The price range is expected to be around 4-6p/kWh. The purpose of this is 'pump-priming' to overcome technical problems and help offshore wind to become viable: "Whilst it is envisaged that in future greater economies of scale offshore will offset the higher costs inherent in the offshore environment, it is recognised that initially offshore wind energy will cost more than onshore wind energy and so would require a separate band within NFFO. However it is hoped this cost difference will quite rapidly disappear..."[22].

5.4.4 Tidal and wave power

Power from the sea has not yet appeared in the NFFO arrangements. Although the potential is vast, technical and environmental problems combined with high costs mean there are no prospects of significant generation in the short to medium term.

5.4.5 Energy from agricultural waste

Waste from agriculture and forestry, and crops grown for fuel, have a large potential as renewable energy sources. There are also considerable additional benefits in disposing of waste in this way, with less damage to the environment, and useful by-products. A study by Griffith and Hicks[23] gives an overview of the UK potential, the technologies involved and the economics of agricultural waste. Table 18 gives the potential for the main forms of waste, showing the dominance of agricultural waste.

Table 18. Potential for development of energy by type of waste.

Type of waste	Generated waste 10^6 tonnes	Calorific value GJ/tonne	Potential 10^6 GJ	Potential %
Agricultural	94	13	1222	76%
Municipal	34	10	340	21%
Chemical	2.5	13	33	2%
Sewage sludge	1	17	17	1%
Clinical	0.35	15	5.25	0%
Total	132		1617	100%

Agricultural waste breaks down in turn as shown in Table 19. Excreta from cattle, pigs and poultry make up more than 80% of the total, with 68% from cattle alone. The total electricity generation potential of 26 TWh is equivalent to 7.5% of the 345 TWh consumed in the UK in 1997.

Table 19. Agricultural waste arising, and energy potential of animal waste.

Category	Amount 10^6 tonnes	Proportion %	Generation potential GWh
Excreta in buildings			
Cattle	64	68%	
Pigs	9	10%	2427
Poultry (plus litter)	5	6.1%	6187
			Total 26176
Other waste			
Straw	13	14%	
Carcasses	0.1	0.1%	
Silage liquor	2	2.1%	
Total	94.1	100%	

There are two ways of arranging generation. The first is a large centralised facility serving several farms. A typical example would be a power station using chicken litter as the feed stock for direct combustion in the range 5-25 MW, sited in an area with a lot of poultry farming such as Norfolk. A mixture of fuels can be used; the largest biomass power station is nearing completion at Thetford in Norfolk. This will burn a mixture of straw, wood chippings and poultry droppings, with a capacity of 38.5 MW, exporting 308 GWh annually to the grid, and subsidised under NFFO 3[24].

The second type of generation is a decentralised plant serving a single farm or small community with an output in kilowatts, and the mode of operation could be direct combustion of dry wastes or anaerobic digestion to produce methane from wet wastes. Waste can be processed in a number of ways, depending on its composition.

5.4.5.1 Pyrolysis and gasification

This is three-stage process of drying, combustion and reduction to produce oil, gas and char. It requires heat, typically supplied by burning carbon monoxide gas which is a by-product. The final products, energy used and energy produced depend on the fuel and the manipulation of temperature ranges etc. in this flexible process. The use of pyrolysis has only recently been considered as a viable process for farm waste.

5.4.5.2 Direct combustion of dry waste

This usually involves drying, partial pyrolysis/gasification and final char burning. A range of fuels have been used, and there is considerable experience of this technology in the UK by 'farm waste to energy' contractors, mainly for poultry waste.

5.4.5.3 Anaerobic digestion

This is used for wet waste, mainly cattle and pig slurry, which is put into closed tanks to produce methane gas. Three biologically distinct types of digestion can be used, in three temperature ranges which lie between 5°C and 70°C. Higher temperatures require more heat input, but the slurry is broken down more quickly. Digestion is usually used with a boiler or CHP system and useful by-products include liquor which can be used as fertiliser, and solid waste for further composting. Capital costs are higher than for poultry litter. Pig slurry is more economic than cattle slurry because pigs are usually kept indoor all year, pigs are farmed more intensively so unit sizes are more applicable to CHP, and the slurry breaks down more quickly. Griffith reported 43 digesters had been installed (1997) and it is thought there is considerable potential in small to large scale intensive farming activities in the sub-MW range. Centralised digesters for large scale power generation are unlikely to be developed in the UK. By avoiding spreading slurry directly onto fields, smells and the pollution of streams and ponds is reduced.

The farm waste to energy contracts under NFFO awarded to date are shown in Table 20, from [23]. Poultry litter is the most well-established source. Coppicing, general non-animal agricultural and forestry waste, and energy crops account for the bulk of generation. Slurry currently only accounts for a very small amount of generation, despite its large potential.

Table 20. Farm waste to energy technology supported under NFFO orders 1-3.

NFFO	Date	Technology	Fuel source	Generation (MW)
1	1990	Direct combustion	Poultry litter	25.4
		Digestion	Slurry	0.1
2	1991	Direct combustion	Poultry litter	30.2
3	1993	Gasification	Coppice	19.0
		Direct combustion	Energy crops, agricultural & forest waste	103.5
		Digestion	Slurry	0.3
			Total	

Table 21 gives the costs for a range of technologies. This shows that poultry litter is the cheapest per kWh, while coppicing is the most expensive. Naturally there are wide geographical variations in the availability of fuels. For example, poultry farming is concentrated in East Anglia, the South West, Yorkshire and Humberside, while forestry is concentrated in the North of England, Wales and Scotland.

Table 21. Capital and operating costs for a range of farm fuel technologies, from[23]

Technology	Capital cost (£/kW)	Operation and maintenance (£/kW)	Load factor (%)	Unit price of electricity @ 8% discount rate (p/kWh)	Unit price of electricity @ 15% discount rate (p/kWh)
Poultry (small)	1500-1800	210-260	70-80	1.5-2.0	4.0-5.0
Farm biogas	2500-3000	100-120	45-90	2.5-3.0	4.5-5.0
Arable coppice	1200-1400	260-318	70-85	5.7-7.2	6.3-8.0

Overall, energy from farm crops and waste has a large potential, but what little of this has so far been realised has been mainly with NFFO support. However, with competitive costs for poultry waste and farm biogas, combined with other environmental benefits, it seems likely that these areas could expand considerably. Since many farms lie on the periphery of the electricity network, there could be technical problems in embedding the larger generators.

5.4.6 Small-scale CHP in multi-residential buildings

The Energy Savings Trust have published an analysis of the future potential for small-scale multi-residential buildings, up until 2010[25]. An estimated 5000 potential sites with communal heating systems were 'easily identified' in 1995, principally in the social housing sector, but so far only 90 of these, less than 2%, have had CHP installed. This appears to be due as much to the complexities of the regulatory and financial arrangements, combined with lack of awareness, as to the economics of the schemes.

There are an estimated one million dwellings with the potential for CHP, including those not currently with communal heating but which could easily be connected in this way. With the domestic market opening up to competition, housing associations and local authorities will be able to sell electricity direct to tenants, which should greatly improve the economics of residential CHP. The report estimates that by 2010, there could be 682000 dwellings (68% of the potential) with CHP. Assuming an average output of 0.5 kW per dwelling, this would represent an installed capacity of 340 MWe. Since the output of each plant would be small and mainly in urban areas, most of the power could easily be absorbed by the existing network.

5.4.7 NFFO-5

On 24 September 1998, John Battle MP, Minister for Energy and Industry, announced the Fifth Non-Fossil Fuel Obligation Renewables Order (NFFO-5) for England and Wales. Comprising 261 projects which total 1177MW Declared Net Capacity (DNC), this is the largest Order since the NFFO began in 1990. It is also the cheapest, with an average price of power of only 2.71p/kWh, compared to the electricity "pool" price of 2.67p/kWh. To put the Order into context, 1177MW DNC is enough electricity to meet the average requirements of 1.4 million homes.

5.5 Required connection for 2010

The "best guess" scenario with central GDP growth, low fuel prices and a 20% carbon constraint with no new nuclear predicts a contribution from renewable generation of 8%. The majority of this capacity comprises: existing hydro, onshore wind and municipal and industrial waste. This would require an increase from 1997 levels of 2.1% (1.26 GW) to 8% (4.8 GW) an increase of 3.54 GW. If the capacity of an average scheme is 5 MW this represents 708 installed schemes requiring connection.

However, if the large potential for offshore wind is realised the contribution increases to 13.5% (8.1 GW) representing an increase of 6 GW. If the average scheme is 50 MW this represents a total of 758 schemes.

Similarly, if the "best guess" scenario fails to materialise, for example if the 20% carbon constraint is not implemented, the majority of the other scenarios predict levels of renewable generation around 4%. This would represent 2.4 GW and 480 schemes.

The unofficial target for CHP generation is 10 GWe, if this capacity is provided using the same mix of generation plant sizes this would represent 2284 schemes requiring connection from 1997 levels.

However, the 10 GWe target seems very optimistic when compared to the current levels of growth and the limited scope for schemes in excess of 10 MWe. Using the 1996-97 growth figure of 4.8% would give CHP capacity of 8 GWe representing 1555 schemes requiring connection.

Therefore the number of renewable schemes that would require connection ranges from 480 to 758 with the "best guess" at 708. The number of CHP schemes ranges from 1555 to 2284 the lower figure being more realistic. This gives the total number of schemes requiring connection ranging from 2035 to 3042 with the most likely scenario of 2263.

6 Solutions to Restrictions

A literature search of INSPEC and other international databases revealed a great many papers on embedded generation and the problems of connecting it to the network. However, there were far fewer on the solutions, and most of these were concerned with new technology rather than practical implementation. Although the databases are international, the vast majority of papers were from the UK. Why this should be is not obvious, but it may be linked to the level of research in electrical engineering in the UK, combined with the liberalisation of the electricity market. The latter makes problems caused by embedded generation involve more than one party, and therefore a lively topic of debate. The situation is likely to be very different where embedded generation, such as large-scale wind farms, is built and connected as a routine process by a large vertically-integrated electricity company. A good starting point from a mainly UK perspective comes from an IEE Colloquium in 1996[26].

6.1 Solutions to technical and planning restrictions

6.1.1 United Kingdom

A paper by Thomas and Welsh[27] discusses the practical issues surrounding connection of embedded generation in the Manweb region. Renewable generation in this diverse region ranges from wind and water power in Wales, to landfill gas, waste generation and CHP in urban areas. They argue that while a developer of renewable energy tends to size the plant according to the energy resource available, there are important advantages in ensuring that the generator utilises the full capacity of the network at a particular voltage level. Many technical issues about the physical connection and control are described with reference to real projects. These include:

- In order to meet planning requirements, use of local building materials for substations, such as stone and slate in rural Wales.
- Lowest cost connection usually means less protection; for example a transformer between generator and network acts as a buffer improving protection, but costs more.
- Voltage control is the main limiting factor on the 11kV network
- Scope for simple tee-off connections is very limited, because of the consequent reduction in reliability for existing customers.
- All large machines should be bus-bar connected.

6.1.1.1 General solutions

The results of the questionnaire and the discussion group on the effects of embedded generation on the existing network highlighted a number of issues which create barriers to the connection of embedded generators. A number of these issues will now be examined and solutions from the discussion group will be presented.

It is important to note that although possible solutions to the different issues associated with embedded generation are described separately in the following sections, in practice many of the issues cannot be considered individually. The issues are invariably inter-related, but, for clarity each issue is described separately here. It should also be noted that the viability for any particular solution depends on other related solutions.

Network Capacity

Presently, with the current low levels of embedded generation, the density of generation connection is low except in some areas and so the occurrence of two independent generators "close" to each other is rare. Thus, up until now, it has been relatively easy to accommodate and connect a single embedded generator of modest size. If the network capacity is exceeded on any item of plant the solution is to uprate all the items of plant whose rating is exceeded. Alternatively there may be scope to adjust the output of the generator to match the available network capacity without having to uprate any of the plant.

When dealing with concurrent applications a contractual solution may be necessary to cater for the winner of the contract race using up all of the network capacity making the second application prohibitively expensive. Some means of sharing the costs between the applicants could help resolve this barrier to connection.

Network Security

P2/5 is the primary design document related to network security and at present was not written to allow embedded generation to make a positive contribution to network security. It may now be the time for a revision of this document to cater for this aspect of embedded generation. This is particularly the case when there are many generators within a scheme.

Some companies are currently considering whether or not there is any merit in developing an islanding policy in relation to improving system security. The Generator would need to be aware of common-mode failures in his generating process in order to accurately guarantee his predicted availability figure. A contract would need to be in place to ensure the generator availability with suitable penalty clauses for lack of availability. In order for RECs to accept power islands, the "power island" itself would take over responsibility for voltage/frequency control. Also, electricity companies would be less willing to rely on indirect loss of mains detection techniques, such as ROCOF and Vector Shift, preferring to see the more reliable (but generally more expensive) Inter-Tripping Relay method used.

Voltage Regulation

Statutory voltages in distribution networks are maintained by controlling the voltage at source substations using on-line tap changers with Automatic Voltage Control (AVC) relays. The voltage range of existing equipment particularly at the low end may not be sufficient to accommodate the effect of embedded generation. There are a number if solutions and potential solutions for the effects on voltage regulation caused by embedded generation. These are described below.

- Extend the voltage range of switchgear affected.
- Deploy tap changers at more locations on the network.

- Operate generators with voltage control, rather than power factor control, although this means the generator may operate at poor power factors and there may be increased reactive power on the network.
- Site the generator closer to the substation so that the voltage regulation impact is minimised, e.g. busbar connection of large machines.
- On rural networks there is the potential to utilise pole mounted voltage regulators.
- Reduce the frequency of sudden generator loss caused by protection relay nuisance tripping. For example loss-of-mains protection relay settings could be modified.
- If the equipment is suitable, modify voltage regulation schemes and tap changers to allow reverse power flow. Note, that in general tap changers and their controllers are not designed to operate under reverse power flow conditions.
- Reduce the impedance between the generator and the primary substation in various ways such as replacing lines or adding new lines and reconfiguring the network or even adding new lines and running part of the feeder in parallel.
- Prevent generator output when the network is configured for fault conditions. During fault conditions a high impedance back feed is often used, this would not be able to handle the same amount of generation and maintain the voltage within the set limits.
- Provide a dedicated line for the generator and specify a non-standard voltage.
- Relax statutory voltage requirements so that under agreed conditions the limits can be breached. This has safety implications and some plant may fail.
- Develop a new device to limit the voltage delivered to a customer to maintain it within the statutory limits. This would be particularly useful on weak networks with high impedance feeders.

Earthing

The Electricity Supply Regulations (1988) repeat the long standing requirement for all public distribution networks to be connected to earth as close to the source as possible. This is to prevent long term overvoltages and minimise risk of electrical shock by providing predetermined paths for earth leakage current to operate protective devices. It also minimises the voltage rise should inadvertent contact occur to a higher voltage system. Most embedded generators do not normally have their neutral point earthed when operating in parallel with a distribution system. A number of technical solutions are available to resolve the problem of multiple earthing of a generator and a PES network. These are described below.

- The use of a transformer with suitably arranged windings.
- Interlocking of switches and automatic earthing of the generator neutral only when the incoming mains is disconnected.

Fault Level

A number of technical solutions and potential solutions are available to resolve the problem of high fault levels caused by embedded generation. These are described below.

- Switchgear ratings can be increased, although sometimes the affects are spread over a significant proportion of the network from the point of connection, making such a solution relatively expensive. This may even impact on other customers.
- Reduce the generator or REC infeed. This can be done in a number of ways such as adding a generator transformer or adding reactors or reconfiguring the network. However, this can have negative impacts such as reducing power quality.
- Isolate the generator from the main REC infeed.
- Install an inter-tripping scheme to disconnect the generation when the system is operating in abnormal conditions.
- Apply fault current limiter technology. New superconducting fault current limiters are being developed by several switchgear manufacturers. Note, EA Technology currently leads a UK consortium to develop such technology.

Asset Utilisation

Embedded generation generally leads to reduced asset utilisation, since the network needs to cope with situations in the future when the generator may not be available. This effect can only really be minimised at the planning and design stages of the generator connection.

Losses

Losses on a given network will largely depend on the location of embedded generators with respect to the major loads and the power flow on the network. Careful consideration at the planning and design stages can optimise the connection of an embedded generator to keep losses to a minimum or perhaps reduce losses.

Stability

To ensure certain generators remain stable during system faults they can be fitted with a stabiliser and the protection may need to be upgraded.

Load Growth Publication

Load growth projections are utilised in long term planning of distribution networks. In an ideal world generators would be located at the optimum position for supplying the areas of load growth. At present a company cannot position a generator with the aid of knowledge about predicted load growth regions. Published load growth data would give generators the opportunity to position generator units where they are most needed and so reduce the potential need to reinforce the distribution network. Guidance would be required from the distributor for the optimum position so that network reinforcement could be avoided. This approach would benefit the distributor by preventing network capital expenditure caused by load growth and generator connections.

Deferred Reinforcement Benefit

Another method, like load growth publication, that could encourage generators to be located in optimal positions is to give financial encouragement for a generator to be able to claim the benefits of deferred reinforcement. Actual reinforcement schemes that are being planned to solve known problems need to be identified in order for such benefits to be realised.

Generator Control by Network Operator

In many situations it would make generator connection viable if control of the generator was taken by the network operator. Scheduling and dispatch would be handled by the network operator. Network reinforcement could be avoided if generator output can be controlled to match available network capacity. In practice this approach is likely to be an 'all or nothing' inter-tripping scheme where export is limited by plant status. There are also implications associated with energy trading arrangements and maybe financial recompense would be needed for the on/off constraints.

Active Export Management

If the current carrying capacity of a circuit restricts the export capacity there is the possibility of actively managing the export depending upon network configuration. It may be possible to measure current at a number of points to establish an export "allowance". Such a system would need to fail safe to protect plant and maintain supplies to consumers. Further investigations for designing, maintaining and testing such a system would be necessary. New methods for modelling an "active export" system are also necessary for assessing connection of additional load or further generation. As generator control is required with this solution there are similar implications to consider associated with energy trading arrangements and financial recompense for on/off constraints.

Generator Control via Contract Obligations

A control solution via contractual obligations is an indirect control of the generator output compared to the direct control that would be achieved by the network operator (above). For example, the contract would specify a limited generator output during low load periods. This might be done dynamically so that the generator is notified as demand reaches a specified low level or by specifying fixed low load periods in advance.

Availability and Financial Penalties

Generator availability could be included as part of contractual obligations so that the distributor could utilise the available capacity in planning calculations. When the capacity is unavailable, according to the contract conditions, then financial penalties are applied to the generating company. Further investigation is required as such arrangements would become complex where multiple generators in a given part of the system were required to provide customers with an acceptable level of security. The technical issues such as protection operation, increased voltage fluctuations and increased harmonics under the reduced fault level conditions would need investigation if local generation is to support the capacity of an 'abnormal' system. There are also energy trading implications similar to generator control solutions.

Cost Sharing

At present there is no mechanism for a distributor to recover costs from a second generator to compensate a first generator connection. Distributors would be neutral if such a mechanism was in place provided that the sharing method was equitable and the costs of managing such a system could be passed on to generators. Some sort of open book arrangement between the parties may be required.

Generators Levy

Establish a financial levy that applies to all embedded generators for distributors to use for associated connection costs. This is one method of cost sharing in that the connection costs would be shared between all generators rather than costs being applied to individual generators.

Distributor Incentives

Give financial incentives that encourage distribution companies to lead the drive towards increased embedded generation, particularly if the generation is from renewable energy.

6.1.2 Ireland

A paper by McTague discusses embedded generation on the Irish network operated by ESB[28]. This has many long line lengths in rural areas with large voltage drops. Technical criteria used elsewhere for embedded generation have sometimes proved inappropriate, and pragmatically adapted to the local situation. For example, a 1% voltage rise caused by the generator at zero network load was originally allowed, based on Danish practice. However, this was found to be too restrictive for most of the network, so more relaxed criteria are applied.

Under the arrangements described (1996) ESB allows embedded generation based on worst-case (minimum) local loading. The author suggests that in the future, control systems which adjust the generator output according to the capacity of the network to absorb that output may be employed. ESB are also extending their SCADA system to all network substations, improving information about network loads, which means local generation can be installed where conditions permit.

6.1.3 The Netherlands

The Netherlands have a very high level of embedded generation, at about 30% of network loading (1996). This led the government to place a moratorium on new embedded generation to allow studies of network stability, although this was later lifted. More than 10 years ago a working group from the Dutch utilities was set up to investigate the problems and solutions for the parallel operation small generators. This is reported in[29], but unfortunately the paper is in Dutch and it was not possible to obtain a translation within the time available. As this is dated 1988, it is likely that new solutions have become available since then.

6.1.4 Denmark

In 1998 Denmark had a total wind generating capacity of 10,000 MW, mainly from onshore wind farms (or 'parks'). The first commercial offshore wind parks are expected to operate from 2002, ranging in size from 120 to 150 MW. Grid connection is not seen as a major technical problem[30]; the main issue is seen as optimising the technical solutions for economic operation.

They plan to use 30-33kV within the parks, connected to an offshore 30 to 150 kV substation and connected to the mainland at 150 kV. The undersea cables will have a high electrical capacitance, which it is thought may be useful to supply reactive power to the parks. Some variable reactive power compensation may also be used. High voltage direct current connection to the mainland is also being considered. Remote surveillance by radio will be used. Companies such as Elsamproject offer consultancy and specialised software for technical analysis of wind parks and their network connections.

6.2 Solutions to financial restrictions

Raising finance for renewable energy projects has never been easy. A variety of methods are used, including private investment in small schemes, grants, loans, equity investment, and community investment. The extent to which these are used varies between countries and the size of the scheme. Some banks specialise in ethical and environmental projects such as renewable generation. These include the Dutch banks Triodos Bank and MeesPierson Bank, which both have a UK branch. After long-established hydro schemes, wind power is the largest 'pure' renewable technology, and it is expanding rapidly. The examples quoted here are all for wind, but other technologies would face very similar problems.

6.2.1 United Kingdom

For wind power in the UK, the Triodos Bank offers both loan finance, and equity investment through shares in the Wind Fund[31]. So far the Wind Fund has raised nearly £1 million for wind energy projects in the UK. By using a bank with an understanding and interest in renewable energy, this type of finance is much easier to arrange than using conventional merchant banks.
Small generators in the UK do not normally obtain good prices for exporting power to their host distribution company. The Renewable Generators' Consortium (RGC) was set up to act as an umbrella organisation in negotiations between NFFO-1 and NFFO-2 contract-holders and electricity suppliers. With these contracts finishing at the end of 1998, the RGC can negotiate collectively to sell their combined output. The RGC has a total capacity of 312MW DNC. The advantages of collective negotiations were threefold: sold in blocks, the generators' power is more attractive to suppliers; generators speaking with one voice are easier to negotiate with; and, acting as a group, the generators could take advantage of more sophisticated trading

arrangements. As a result, most of the generators will receive prices that are typically 10-20% higher than those they would have obtained negotiating individually.

Customers with on site generators who export to the local network have to pay DUOS charges. In order to avoid these, Woking Borough Council set up a private wire scheme[32] supplied from its own CHP plant, which also produces heat for domestic heating. There is a connection to the local distribution system for top-up and stand-by power. Although the local REC charges more for imported power than it pays for exported power, the schemes are still in credit with the REC. Woking Council is prevented from becoming a full Energy Services Company (ESCO) by central and local government rules on finance. Therefore they are setting up a joint venture ESCO with Entergy/London Electricity to bring in private sector financing for local communities. Such schemes also have the advantage of removing many of the technical problems caused by direct network connection.

6.2.2 Germany

Since 1991, wind power producers in Germany have been supported by being paid 90% of the average domestic electricity price for their output. There are many wind turbines in the windier north, up to half owned by farmers, and around 100,000 people directly involved in wind energy as owners or shareholders[33]. As well as private finance and ecological banks, there are many community finance schemes, and support from the strong regional governments.

6.2.3 Italy

A large wind farm cluster on the hills of southern Italy is being developed by the Italian company IVPC[34], involving finance totalling 211 million ECU. Current capacity is 82 MW, with a further 87 MW to be constructed. Incentives have included a premium payment for output of 10.5 ECU cents for the first eight years, after which the premium is halved. Because it is a poor region, there is also a 10 year corporation tax break. The local communities have benefited through employment, and 1.5% of gross income going to the local council. One of the most difficult aspects of the project was arranging grid connections with ENEL in an area where the infrastructure is poor. IVPC is having to contribute a third of the connection costs, that is about 4 million ECU, and a similar amount for the construction of substations.

7 Conclusions

In recent years the deployment of new and renewable energy technologies has gathered pace, stimulated by the DTI's New & Renewable Energy programme, and the Non Fossil Fuel Obligation (NFFO). At the same time, privatisation and the removal of the Electricity Industry's monopoly has opened up the market to private generation. The net result has been an increase in the number of small-scale conventionally-powered embedded generators as well as a heightened level of interest in renewable technologies. This report has considered the effect of increasing levels of embedded generation on the distribution network and the conclusions are presented below:-

- The operating environment for electricity companies in the UK can be considered to comprise three elements. The legal framework created by acts of Parliament, the regulatory framework determined by the Public Electricity Supply Licence and regulated by the OFFice of Electricity Regulation and the operational framework defined by numerous electricity industry standards.

- Technical designs for generator connection are normally handled by the Planning Departments within the electricity companies. The guiding principles for the new connection are: meeting the requirements of the Distribution Code and Grid Code, ensuring the security of supply to other customers is not prejudiced, ensuring the quality of supply to other customers is not prejudiced, ensuring plant on the network operates within its rating and meeting the appropriate technical standards.

- Although all of the electricity companies are operating within the same framework the relative importance of different aspects varies from company to company, e.g. details required from the generator, fees charge for indicative costings, effective start dates of the application, the issues addressed in indicative costings, the issues addressed in firm costings, etc.

- The connection of embedded generators to the network has numerous effects on a network designed for power flow in one direction. Many of the effects create barriers to the connection of more embedded generation. The issues highlighted in this report include: fault level, voltage control, reverse power flow, protection grading, stability for larger generators, voltage profile, network capacity, network security, earthing, asset utilisation and losses.

- The “best guess” scenario for the required connection of renewables for 2010 has central GDP growth, low fuel prices and a 20% carbon constraint with no new nuclear. This scenario predicts a contribution from renewable generation of 8%. If the capacity of an average scheme is 5 MW this represents 708 installed schemes requiring connection. The most likely scenario for CHP using the 1996-97 growth figure of 4.8% would give CHP capacity of 8 GWe representing 1555 schemes giving a total of 2263 schemes requiring connection.

- The Generators believe that the market discriminates against them Indeed the infrastructure costs, especially for renewables generation is a particularly severe barrier to implementation. It is necessary for the REC to pass on all of the costs associated with the network connection, inducing capitalised maintenance for the lifetime of the additional equipment, as part of the up-front cost that the Generator has to bear. This is because the REC has no guaranteed income from the Generator in the future.

- There are many solutions to the technical problems caused by embedded generators, however many of the technical solutions invariably create a financial barrier to generator connection due to the costs associated with them or another technical barrier such as reduced security of supply or poor quality of supply.

- Many of the solutions and recommendations documented in this report will be affected by regulations, either forced regulation or driven by various regulated performance measures. It is also reasonable to expect that the regulations will change over time and this will further impact on the way embedded generation affects the distribution network.

- There is no centralised planning for embedded generation in the UK and the business drivers for embedded generators are varied. For the foreseeable future there will be no government or regulated policy for embedded generation and so distribution companies will continue to be reactive to the impact of embedded generation rather than proactive.

- There is no incentive for distribution companies to encourage embedded generation. No revenue is directly available. Although a theoretical reduction in network losses is often quoted as a positive impact for a distributor, it is not calculated because it is not necessarily reliable.

- UK distribution networks have been designed, constructed and operated over many years for large, centrally dispatched generation. The networks are not designed, constructed or operated for small, localised, embedded generation. Furthermore, independent generators site a generator for their purposes, not considering the optimisation for distribution systems and therefore the embedded generation is appearing on distribution systems in an ad-hoc manner.

8 Recommendations

During the research for this report a number of areas have been highlighted by the participating companies that would benefit from further work. These areas are described below.

Combined technology, financial and contractual investigations

Identify new areas for investigation that focus problem solving into combined solutions. The various technical, financial and contractual solutions all inter-relate and so an overall project structure should be applied, as an umbrella over a number different investigations. Solutions would involve technology issues in economic assessments and concentrate also on the financial and contractual structures that could lead to optimal embedded generation connection scenarios.

For example a method to offset costs associated with technical solutions would make connection viable. Costs would have to be transferred from the generator to electricity consumers or be paid for by government subsidy or come from a generators levy. However, electricity consumers would benefit over time because of reductions in network reinforcement and network losses leading to lower prices.

Network security and design guidelines

Many of the technical issues surrounding the connection of embedded generation are well documented. However, there may be merits in establishing design guidelines for each type of embedded generation so that positive impacts can be included in network design, such as the contribution that many small embedded generators could make to network security. Alternatively, if different levels of network security are acceptable then networks could be isolated to utilise local embedded generation. The distribution network then provides backup supply that is less secure than it would be using the current P2/5 standard. Detailed risk and economic studies are necessary if different levels of network security are to provide a way forward.

Fault current limiters

A trial of new superconducting fault current limiters is recommended to assess capability for resolving fault level issues with connected embedded generation.

9 Acknowledgements

This report is published with the permission of the EA Technology Director of Research and Development. The project was funded by the Electricity Companies - participating in Optional Module 5 - Embedded Generation, of the Strategic Technology Programme (STP) and ETSU. The Authors wish to acknowledge assistance of the companies who contributed by completing the questionnaire and participating in the discussion meetings.

10 References

[1] UK Energy Act, 1983.

[2] Electricity Supply Regulations, 1988.

[3] The Electricity Act, 1989.

[4] The Distribution Code, 1998.

[5] The Grid Code, Revision 25, The National Grid Company plc, August 1998.

[6] Engineering Recommendation P.2/5 *"Security of Supply"*, 1978.

[7] Engineering Recommendation G.5/3 *"Limits for harmonics in the United Kingdom electricity supply system"*, 1976.

[8] Engineering Recommendation P.28 *"Planning limits for voltage fluctuations caused by industrial, commercial and domestic equipment in the United Kingdom"*, 1989.

[9] Engineering Recommendation G59/1, Amendment 1 *"Recommendations for the connection of embedded generating plant to the regional electricity companies' distribution systems"*, 1995.

[10] Engineering Technical Report ETR 113, Revision 1 *"Notes of guidance for the protection of embedded generating plant up to 5MW for operation in parallel with public electricity suppliers' distribution systems"*, 1995.

[11] Engineering Recommendation G75 *"Recommendations for Embedded Generation Plant to Public Electricity Suppliers' Distribution Systems above 20kV or with Outputs over 5MW"*

[12] "Digest of United Kingdom Energy Statistics 1998", Department of Trade and Industry, The Stationery Office, London, 1998.

[13] "Renewable Energy in the UK: Policies for the future", C. Mitchell, Council for the Protection of Rural England, February 1998.

[14] "Potential impacts of micro chp on electricity companies", , EA Technology Ltd., report 4437, project S0004, May 1998.

[15] "An assessment of renewable energy for the UK", Energy Technology Support Unit, HMSO, London, 1994.

[16] "Energy paper 65: Energy projections for the UK", Department of Trade and Industry, HMSO, London, March 1995.

[17] "Modelling work in support of the new and renewable energy programme using Markal", Energy Technology Support Unit, RYCA\18504085\R1, Harwell, April 1996.

[18] C. Bates and P. Watkins, "The potential for sustainable energy in the UK", International Institute for Energy Conservation, London, June 1997 [source reference not given].

[19] "The United Kingdom demand for renewable electricity in a liberalised market", R. Fouquet, Energy Policy, Vol 26 No. 4, pp281-293, 1998.

[20] "The future for renewable energy", EUREC agency, James and James, London, 1996.

[21] "Wind energy: power for a sustainable future", Policy statement of the British Wind Energy Association, 1996.

[22] "A consultation paper on incorporating offshore wind energy into future NFFO arrangements", Department of Trade and Industry, September 1998.

[23] A.J. Griffith and W. Hicks, "Agricultural waste to energy - a UK perspective", Energy and Environment, Vol 8 Issue 2, 1997.

[24] "CADDET Renewable Energy Newsletter", Issue 3/98, September 1998, UK contact: Centre for Renewable Energy, ETSU.

[25] "Small scale multi-residential CHP and environmental benefits to 2010", Energy Savings Trust, London, June 1998.

[26] "Colloquium: The impact of embedded generation on distribution networks", Power Generation Group P10, Colloquium, Inst. Electrical Engineers, London, October 1996.

[27] PG Thomas and J Welsh, "A REC's experience of embedded generation within its networks", Ibid.

[28] "Embedded generation: ESB distribution network considerations", Ibid.

[29] "Results of the VDN-working group study into decentralised electricity generation", Elektrotechniek vol 66 no 8, p722-31, August 1988 (in Dutch).

[30] "Grid connection of offshore wind parks", Danish Wind Power Association, from www.windpower.dk

[31] S Roberts, "Taking the pain out of small-scale wind funding", Wind Directions July 1998, European Wind Energy Association.

[32] "Power full dinosaurs", A Jones, Green Government, Winter 1998, Partnership Media Group.

[33] C Aubrey, "Sharing out the wind dividend", Wind Directions July 1998, European Wind Energy Association.

[34] "Project profile: Campania and Puglia, Southern Italy", Wind Directions July 1998, European Wind Energy Association.

Appendix I

Design Principles and Technical Restrictions relating to the Connection of Embedded Generators

Questionnaire

Introduction

This questionnaire has been produced as part of Project S0515 which is contained in Module 5 (Embedded Generation) of EA Technology's Strategic Technology Programme (STP). The objective of the project is to examine the impact that increasing amounts of embedded generation will have on the technical and commercial development of the network, together with the implications for the way in which the network is operated. This will be of growing importance as the government considers what is necessary and practical to achieve 10% of the UK's electricity needs from renewables by the year 2010. The project is part funded by ETSU/DTI and the final report will be circulated beyond the electricity supply industry . It will aim to give a clear understanding of the impact of embedded generation on electricity companies, with a view to educating those outside the industry and influencing government thinking. The purpose of this questionnaire is to establish the current principles adopted by network designers when dealing with requests to connect embedded generators to the existing network and to identify the main technical restrictions associated with connecting embedded generators to the existing distribution infrastructure.

Completed questionnaires should be returned by 23 October 1998 if possible (using the envelope provided) to:
Mrs Mair Green, EA Technology, Capenhurst, Chester, CH1 6ES.

Replies will be treated with strict confidentiality and company anonymity will be maintained within the broad summary/conclusions drawn from the survey. Thank you in anticipation for taking the time to complete the questionnaire.

Personal Details *(Please complete)*

Name:

Position:

Company:

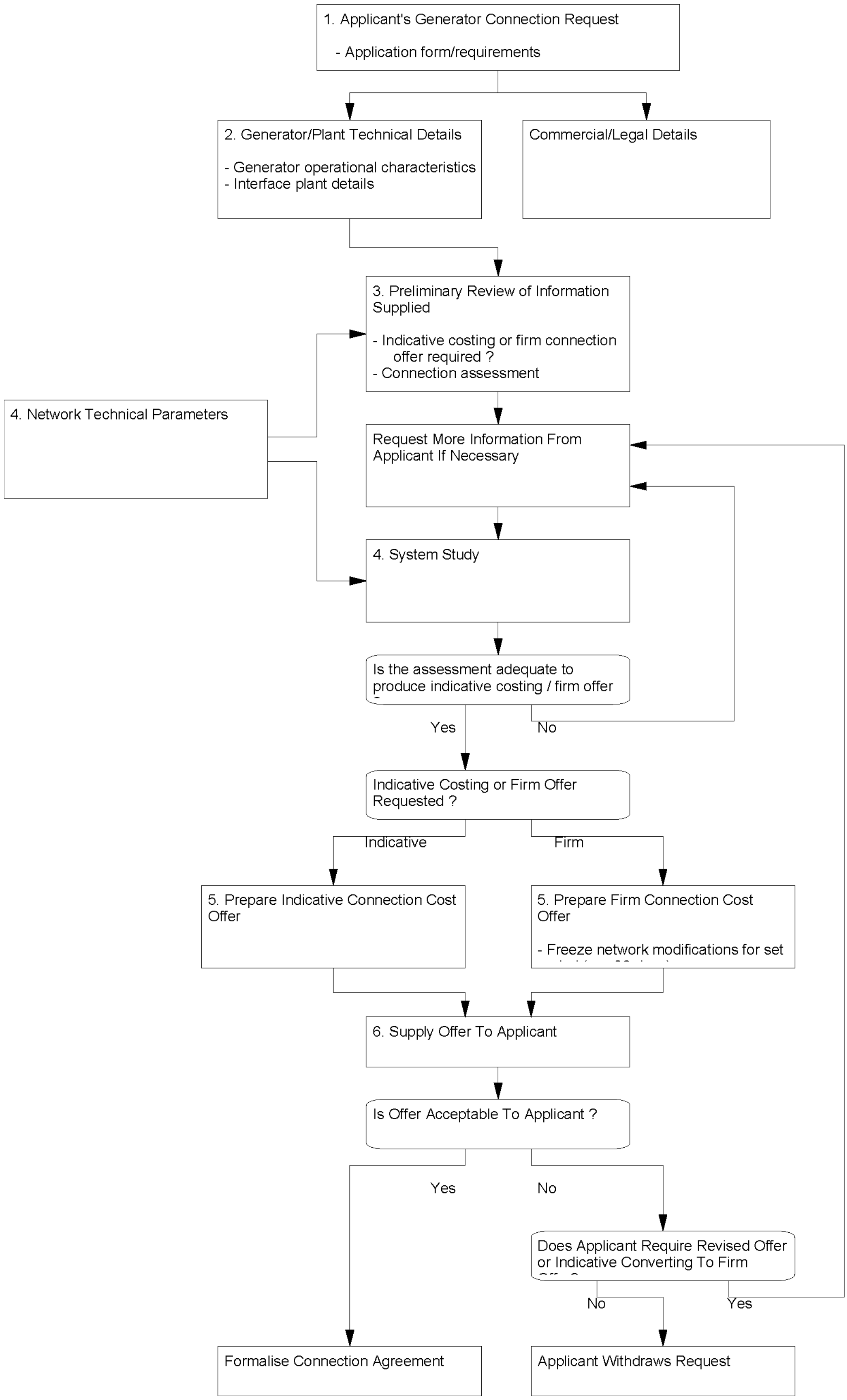
Address:

Telephone:

Fax:

Flowchart

A flow chart has been produced (see over) that attempts to summarise the technical aspects of the application process in a generalised frame work. If, having examined the flow chart, you feel that it is not representative of the sequence adopted within your own organisation for processing generator connection requests, please mark up the modifications on the chart and return it with the completed questionnaire. The individual sections on the questionnaire broadly correspond to the main activities shown on the flow chart.


1. Applicant's Generator Connection Request
- Application form/requirements
2. Generator/Plant Technical Details
- Generator operational characteristics
- Interface plant details
Commercial/Legal Details
3. Preliminary Review of Information Supplied
- Indicative costing or firm connection offer required ?
- Connection assessment
4. Network Technical Parameters
Request More Information From Applicant If Necessary
4. System Study
Is the assessment adequate to produce indicative costing / firm offer
Yes
No
Indicative Costing or Firm Offer Requested ?
Indicative
Firm
5. Prepare Indicative Connection Cost Offer
5. Prepare Firm Connection Cost Offer
- Freeze network modifications for set
6. Supply Offer To Applicant
Is Offer Acceptable To Applicant ?
Yes
No
Does Applicant Require Revised Offer or Indicative Converting To Firm
No
Yes
Formalise Connection Agreement
Applicant Withdraws Request

Section 1 - Application

The following questions are intended to ascertain how an application is initially processed on receipt.

1.1. Does your company have a standard application form for applicants wishing to apply to connect their generator to your network? [Yes] / [No]
(If yes, please supply a copy).

1.2. Within your company, is the application process commercially driven or technically driven ? (Please tick)

[ ] commercially
[ ] technically

1.3. Is any consideration given to the technical competence, capabilities or past experience of the applicant in terms of installing and operating electricity generation equipment (i.e. applicant vetting)? [Yes] / [No]

If yes, please explain briefly what assessment is made and what influence it may have on any connection offer that is made (i.e. level of permitted operations, control responsibility etc.)

____
____
____
____
____

1.4. In terms of the offer to be made to the applicant, what normally determines the exact physical point of connection to the network?

[ ] Applicant's requested point of connection taken at face value, or
[ ] Application examined by PES Engineer whose knowledge and experience is used to determine most appropriate point of connection

1.5. If during the early stages of examining the application it became apparent that a more appropriate point of connection existed than the one requested by the applicant, would this information normally be conveyed to the applicant as a matter of course ? [Yes]/[No]

Section 2 - Generator/Interface Plant Technical Details

The following questions aim to establish what technical information would normally be required from the applicant in order to process the application.

2.1. In the table below, what is the *minimum level* of technical detail relating to the generator and interface equipment that must be supplied by the applicant in order to process the application ?

Note: Because the technical detail required is likely to depend upon the capacity of the generator (MW) and/or the connection voltage (kV), three columns are provided in the table below. Please enter the appropriate capacity/voltage ratings at the head of each of the columns that correspond to the classification regime that you would normally use to group generator installations when assessing connection request applications.

Then rank each parameter within each of the generator classes with one of the following letters:

E - Essential **D** - Desirable **N**- Not required

Generator/Interface Plant Technical Details

	Generator Class by Capacity / Connection Voltage		
Please enter size and/or voltage range:	...........MW ....kV	.........MW ....kV	.........MW ....kV
Parameter			
Site Details			
Location address			
National grid reference (NGR)			
Voltage at point of connection			
Plan			
Generator Details			
Number of sets			
Generator type (i.e. synchronous/asynchronous)			
Prime mover control/speed governor detail			
Generator terminal voltage			
Generator rated output (MW)			
Generator rated output (MVA)			
Generator minimum output (MW, MVA)			
Operating power factor band			
Preferred operating power factor			
Maximum active power sent out			
Controller type (PV/PQ)			
Inertia constant (MW secs/MVA)			
Direct axis reactances			
Quadrature axis reactances			
Direct axis time constants			
Generator Transformer Details			
Rating (MVA)			
Winding ratio			

Primary voltage			
Secondary voltage			
Impedance			
Transformer tap arrangements			
Vector group			
Earthing arrangements			
Zero sequence resistance/reactance			
Interface Equipment Details			
Earthing arrangements			
Connection/disconnection arrangements			
Metering arrangements			
Others: (*please specify*)			

Please rank each parameter within each of the generator classes with one of the following letters:
***E** - Essential* ***D** - Desirable* ***N**- Not required*

2.2. What information is required concerning the applicants intended mode of operation? Please enter: **E** - Essential **D** - Desirable **N**- Not required

[ ]Maximum import/export requirements.
[ ]Percentage of full rated capacity will the generator typically operate at.
[ ]Anticipated output regime (i.e. continuous, intermittent, peak lopping)
[ ]Requirements for top-up or standby supplies (MVA)
[ ]Load management arrangements made to prevent network voltage exceeding statutory limits when the generator is scheduled to be off-line (i.e. for maintenance).
[ ]Load management arrangements made for unscheduled stoppages (i.e. breakdown).
[ ]Level of security required

Please specify any other not listed above:

____
____
____
____
____
____

Section 3 - Preliminary Review of Information Supplied

This section deals with the start of the application process.

3.1. In terms of the PES licence, at what point in the application process is the formal starting point for the application deemed to have been reached (i.e. initial contact with applicant, receipt of adequate information) ?

3.2. If the applicant initially requests an *indicative connection cost* (i.e. feasibility study with caveats for budget purposes only), and later goes on to request a *firm quotation* for a formal offer of connection, which request would be treated as the effective starting point for the application ?

3.3. Would the applicant normally be advised in writing of the effective starting date ?

Section 4 - System Study

It is recognised that the level of detail called for within a system study will depend upon whether the applicant requests an *indicative connection cost* with caveats (for budget purposes only), or a *firm quotation* for an offer of connection. This section aims to establish the difference in the level of detail required for each.

4.1. What are the objectives and main output from a System Study?

For an indicative connection costing:

____
____
____
____
____
____

For a firm connection cost offer:

____
____
____
____
____
____

4.2. What are the issues normally assessed during a System Study? (Please tick as appropriate)

Issue	**Indicative Costing**	**Firm Offer**
Location		
Connection arrangement		
Existing generation capacity		
Existing network equipment ratings		
Control - synchronisation and interlocking		
Protection		
Earthing		
Fault level		
Stability		
Voltage control		
Islanding		
Load flows		
Operational implications		
Impact on NGC		
Others (Please specify)		

4.3. What specific issues present technical problems that are particularly difficult to surmount and therefore create barriers to connection at any particular voltage level?

4.4. Are there any internal/external written guidelines (i.e. Recommended Practices) that are followed as part of the decision making process during the System Study?
[Yes] / [No]. If yes, please specify:

4.5. Will the applicant normally be charged a fee to cover the costs of the system study for:

a) an indicative costing [Yes] / [No]
b) a firm offer [Yes] / [No]

4.6. To what degree would your company be prepared to modify its network operation, possibly to the detriment of other customers, in order to reduce the cost of connection to a generator ?

4.7. How are concurrent applications that affect the same part of the network treated (i.e. where the local transformer would not be capable of exporting both machines but there is a risk that both may not be connected) ?

4.8. When an offer is made, how much technical detail for the proposed connection is shared with the applicant?

Any Other Comments :