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MICROGRIDS
A GUIDE TO THEIR ISSUES AND VALUE

Prepared For Highlands And Islands Enterprise
in Partnership with Scottish Government

Author: Nigel Scott
Verifier(s): Jeff Fodiak, Marc Smeed
Approver: Nigel Scott

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NOTES

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Enquiries should be directed to Xero Energy Limited, 60 Elliot Street, Glasgow G3 8DZ, UK.

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ACRONYMS

Acronym	Full Term
AC	Alternating Current
ANM	Active Network Management
CAT	Centre for Alternative Technology
CHP	Combined Heat and Power
DC	Direct Current
DNO	Distribution Network Operator
GB	Great Britain
HIE	Highlands and Islands Enterprise
IDNO	Independent Distribution Network Operator
km	Kilometre
kV	Kilovolt
kVA	Kilovolt-ampere
kW	Kilowatt
LV	Low Voltage
ms	milliseconds
MV	Medium Voltage
MW	Megawatt
O&M	Operation and Maintenance
OFGEM	Office of Gas and Electricity Markets
PCC	Point of Common Coupling
PV	Photovoltaic
SPD	Scottish Power Distribution
SHEPD	Scottish Hydro Electric Power Distribution
UPS	Uninterruptible Power Supply
USA	United States of America
XE	Xero Energy Limited

EXECUTIVE SUMMARY

General
This report has been produced by Xero Energy Limited (XE) on behalf of Highlands and Islands Enterprise (HIE) and Scottish Government to provide a guide to microgrids. The aim is to assist in the understanding of microgrids, their issues and value. The scope is to provide sufficient context as to what constitutes a microgrid, set out key issues, identify the advantages and disadvantages of microgrids and put this into the context of Scotland and the Highlands and Islands region, and the wider regulatory frameworks that influence microgrid development.

Microgrids in general
The term microgrid can be used to denote a small, usually privately owned and operated, grid irrespective of its actual connection arrangements with the main (public) grid – this includes 'private wire' systems which are permanently connected to the main grid and island systems which are never connected to the main grid. In addition, there are microgrids that can operate in both modes (connected to and islanded from the main grid) – this latter more flexible microgrid is the internationally recognised definition of a microgrid, termed a true microgrid hereafter.

True microgrids
True microgrids are small grids with generation and demand that can run connected to or islanded from the main grid. They offer a key advantage of improving security of supply (keeping the lights on) locally. This means that when problems occur in the main grid, the microgrid can disconnect and continue to operate. True microgrids can also operate to improve power quality, an issue for high value and sensitive consumer loads, e.g. by acting to reduce voltage unbalance, fluctuations, excess range or harmonics.

Given the arguably relatively high level of local security of supply attained in Scotland, and the ready availability of cost effective alternatives to a microgrid when the main grid is lost, e.g. back-up diesel, it is not clear how much benefit is currently brought by a true microgrid considering its likely overall cost and complexity.

As far as XE is aware, there is at time of writing only one such operational true microgrid in the UK (at the Centre for Alternative Technology (CAT), in Wales).

Private wire systems
Private wire systems (normally permanently connected to the main grid) offer a number of advantages but costs and complexity need to be carefully considered. The main driver for private wire systems in Scotland appears to be in circumventing main grid constraints on generation export by using electricity locally and privately. This then allows connection of new (renewable) generation beyond which would otherwise be possible.

An additional advantage is that of local electricity supply whereby the renewable generation is traded locally at prices which can be more attractive than using the GB Market and licensed suppliers. A licensed supplier is however still needed for electricity exchanges with the main grid although their role can be much reduced.

A private wire system is more likely to be cost effective if the wires are run over a small area, kept to low voltage and are not replicating an existing distribution system. Sensible matching of load and generation and use of low cost technology also helps.

Island systems
Island systems are not uncommon in Scotland, e.g. Scottish islands such as Fair Isle. As island systems, they necessarily exhibit many of the features of a true microgrid in terms of demand and generation flexibility and control. They are generally a product of demand for electricity in places where the existing main grid is too far away for a connection to be economic.

Regulatory issues
Key regulatory issues are in ensuring projects are aware of and can avail themselves of class exemptions from being licensed and that even with licence exemptions, projects are aware that they do have obligations. One important issue is the rights of consumers within a microgrid to choose their electricity supplier, meaning the microgrid needs to be able to facilitate third party electricity supply across its wires unless it can demonstrate this is not feasible and not in the interests of the consumers.

Technical issues
Technical issues are more serious for true microgrids and island systems where control of the microgrid and its demand and generation is important. True microgrids must additionally be able to operate in two key control modes – connected to the main grid and disconnected from the main grid in island mode. Private wire systems that are permanently connected to the main grid are simpler but still need considerable technical input.

Costs
Costs need to reflect the different phases of a project, broadly development, construction, operation and decommissioning / end of lifetime. Costs for true microgrids and island systems will tend to be higher as the level of complexity is higher involving more design, more control equipment and costs of control actions such as controlling (constraining) generation, switching consumer demand or using storage technology.

Added value
There are quite a few other aspects to consider in microgrids, some of which are not within the scope of this report, e.g. funding sources, financial models, consenting, etc. As microgrids can be expensive (but not necessarily so) it is important to seek to add value to the microgrid beyond, for example, circumventing a constraint on generation export to the main grid. Examples of this include reduction of the use of fossil fuels used for transport and heating, and promoting new local businesses through local energy supply.

Longevity and innovation
Situations such as main grid constraints can change over time and private wire microgrids may find they can connect new or further generation in the future, may find demand increases or may have to mitigate consumers leaving the system or created businesses failing. Microgrid projects therefore need to be forward looking beyond immediate time horizons to be able to embrace potential future opportunities but also to mitigate risks.

Despite this, there is a substantial shift in the electricity sector towards technology and practices that are being seen now at small scale community level such as local supply models, flexible demand, private wires and storage. There is therefore an element of leading edge innovation in many microgrids, the value of which also needs consideration, e.g. in being able to translate the small scale community initiatives to a wider market.

1 Introduction

1.1 General

This report has been produced by Xero Energy Limited (XE) on behalf of Highlands and Islands Enterprise (HIE) and Scottish Government to provide a guide to microgrids. The aim is to assist in the understanding of microgrids, their issues and value. The scope is to provide sufficient context as to what constitutes a microgrid, set out key issues, identify the advantages and disadvantages of microgrids and put this into the context of Scotland and the Highlands and Islands region, and the wider regulatory frameworks that influence microgrid development.

This report is not exhaustive, as a complete understanding of microgrids, their issues, advantages and disadvantages would be a wide ranging multi-disciplinary exercise. This report is focused on electrical, grid, energy system and regulatory aspects, these being the key functions of a microgrid. Heat networks are touched upon but not expanded upon in any detail, being an energy interface to an electrical microgrid rather than a microgrid per se.

This report covers microgrids in general terms and includes some international examples in explaining microgrids, but focuses on schemes that are typically community driven in terms of the Scottish context.

1.2 Report format

This report is organised with the following layout.

- Section 1 Introduction
- Section 2 Grids and microgrids
- Section 3 Microgrid case studies
- Section 4 Key issues of a microgrid
- Section 5 Microgrids in the HIE region and Scottish context
- Section 6 Microgrid value
- Section 7 Summary
- Section 8 References

2 Grids and microgrids

2.1 Introduction

This section introduces the concept of a grid, sets out how the electricity industry in Great Britain (GB) is structured, sets out what a microgrid is and explores the different types of grids often termed microgrids.

2.2 What is a grid

Before setting out what a microgrid is, it is useful to understand the components of grids in more general terms. A grid in broad terms is a collection of generation and demand (load) interconnected by wires. Grids can be very small, e.g. island systems such as the Scottish island of Fair Isle, or much larger, e.g. the GB national system or the continental European system. These grids all contain generation, transmission and/or distribution infrastructure, and demand. They all require control and a system of governance as to their operation and use.

Larger grids (to which microgrids may be connected) are often referred to as the ‘utility grid’, ‘macrogrid’, ‘main grid’ or ‘large grid’. For the purposes of this report the term ‘main grid’ will be used to denote the GB national system of transmission and distribution currently owned and operated by licensed entities, or its international equivalent.

Connected to the main grid are domestic, commercial and industrial premises, with flows of electricity normally metered at ownership boundaries. These premises can be generators, demand customers or a mix of both.

The main grid will operate under various regimes depending on jurisdiction. The general trend is to an increasingly open market approach. A schematic of the main grid arrangements showing the traditional model of centralised large generators connected to transmission ultimately transferring electricity to consumers via distribution networks is shown in Figure 2-1. This traditional model is changing as increasing amounts of generation, particularly renewable generation, are connected at distribution and within consumer sites.

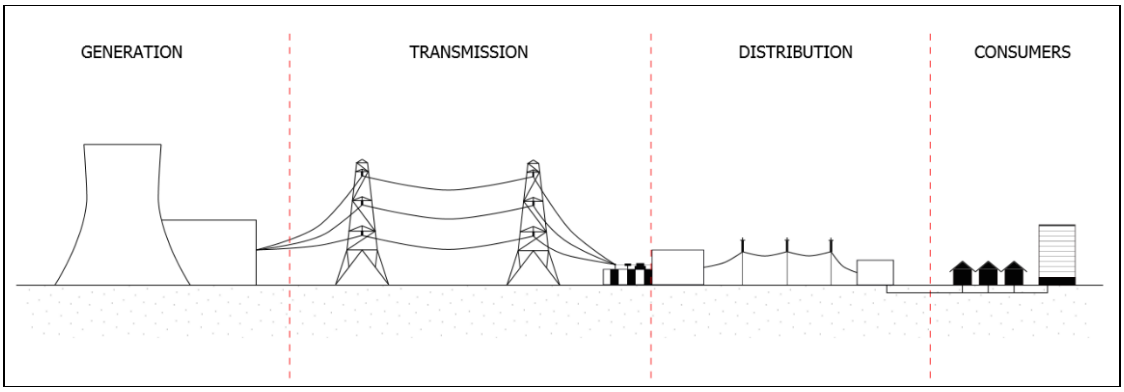

Figure 2-1: Traditional main grid set-up

2.3 The structure of the electricity industry in GB

2.3.1 Electrical flows

The GB main grid will normally refer to the national electricity system owned by the various Distribution Network Operators (DNO), Independent Distribution Network Operators (IDNO), onshore Transmission Owners and Offshore Transmission Owners. The National Electricity Transmission System is operated by National Grid Electricity Transmission in its role as National Electricity Transmission System Operator. All of these parties are licensed under law and regulated by the current Authority, the Office of Gas and Electricity Markets (Ofgem), to undertake their roles around transmission and distribution of electricity.

The obligations of the transmission and distribution businesses end at the ownership boundaries to other parties, namely generators and demand side customers (or consumers). These boundaries are normally metered (to record electricity flows).

Generation is separately owned and licensed with generation connecting at both transmission and distribution. Smaller generators can be licence exempt and this is very common as exemptions can apply up to 100MW.

The physical flows of electricity (energy) are normally from generators, through the transmission and distribution systems to demand side customers (consumers), although there has been and continues to be an increasing amount of generation connected at distribution level and within consumer premises connected to the distribution system. There are also some (e.g. large industrial) consumers connected directly at transmission level, some of which contain generation.

The GB main grid normally operates as a single interconnected entity within a consistent legal, regulatory, technical and commercial framework.

2.3.2 Electricity market

Electricity is sold into and bought from the GB electricity market by way of supply organisations (suppliers), which are licensed. Generators sell electricity to suppliers and consumers purchase electricity from suppliers. Consumers cannot (normally) purchase electricity directly from a generator.

The GB market concept does not follow the actual physical flow of electricity. Instead, the concept is that a generator anywhere in the country can sell its electricity to a supplier. That same supplier can then sell electricity to any consumer in the country. Generators and consumers are free to choose which supplier(s) they buy and sell electricity from. Figure 2-2 shows this separation of physical electrical flows from the GB market for buying and selling electricity.

The electricity market is overseen by Elexon, which performs a settlement process reconciling actual metered volumes of electricity against the contractual positons declared in advance. National Grid Electricity Transmission in its role as National Electricity Transmission System Operator is responsible for physically balancing the system in real time to ensure that the generated and consumed amount of electricity is matched.

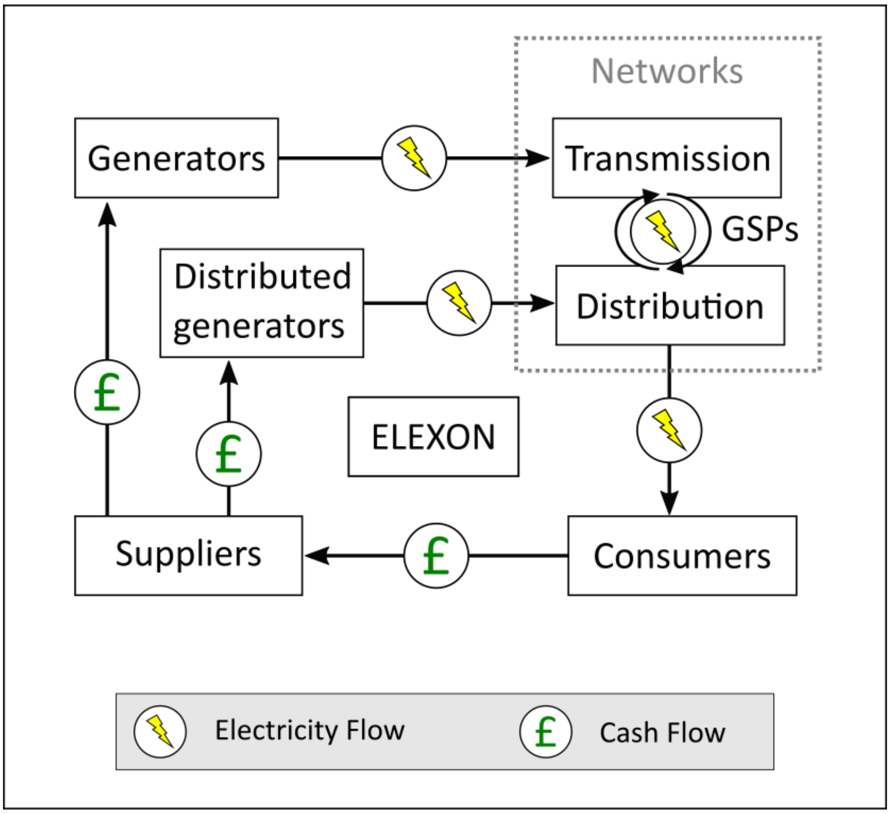

Figure 2-2: Schematic of the GB electricity system and market

2.3.3 Licence exemptions

As noted above, generator licence exemptions are very common for smaller generators. However, licence exemptions are also available for distribution and supply of electricity. This is particularly relevant to microgrids where these functions may be undertaken at a local level and on a small scale. This is discussed further in Section 4.6.2.

2.4 Definition of a true microgrid

A microgrid is most commonly defined as a small electrical grid interconnecting local generation together with local load and, most importantly, with the capability of running both connected to and autonomously (islanded) from the main electrical grid. Figure 2-3 shows a microgrid schematically, with some of the components that it might contain.

➔ A microgrid is a small collection of generation and load interconnected by a 'local' grid which can run both connected to or in isolation of the main electrical grid.

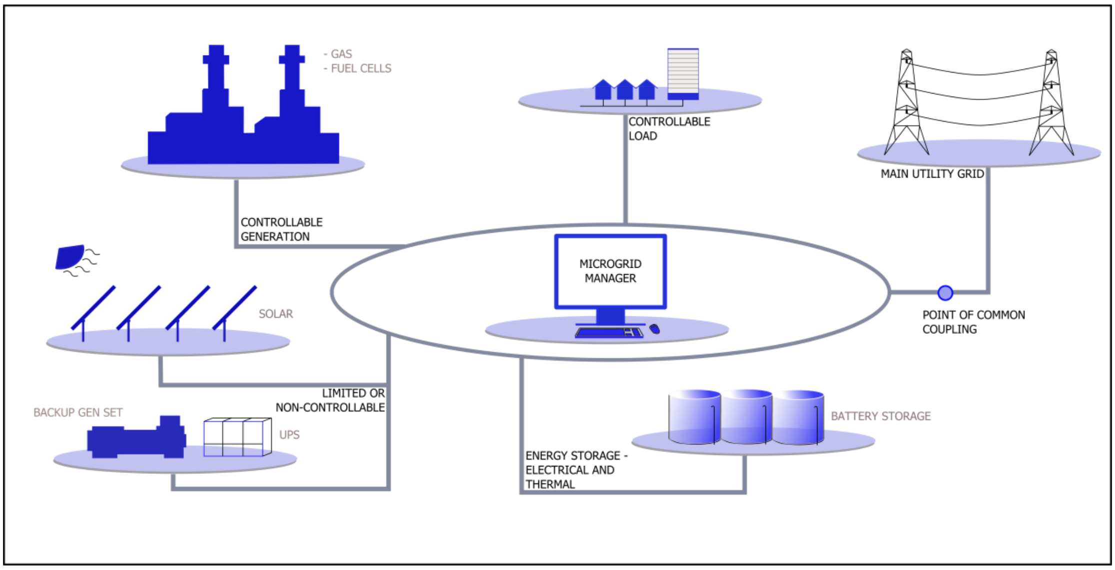

Figure 2-3: High level schematic of a microgrid

"Small" will typically imply anything up to a village, commercial estate, hospital or university campus, or equivalent local area. This is noteworthy as much larger grids also exhibit the capability of running interconnected or in isolation but are not considered microgrids. There are a few other common features necessary in a microgrid worth noting at this point.

- One or more points of connection/disconnection to/from a main grid. These are commonly termed Points of Common Coupling (PCC). PCC will normally utilise switches (e.g. circuit breakers) for connection/disconnection purposes. PCC is a recognised electricity industry term in the United Kingdom which usually denotes an ownership and/or metering boundary and hence can be applied to the microgrid concept, as also shown in Figure 2-3.
- The ability to operate at least some generation, load and other components, in a controllable and coordinated fashion, either while connected to the main grid or when operating independently (when control is an absolute necessity).

The above definition is widely recognised internationally. However, the term microgrid is still often applied to other small grids in various contexts. Two typical and relevant examples for Scotland are discussed overleaf in Section 2.5.

2.5 Other small grids often termed microgrids

2.5.1 Permanently connected grids

Small grids permanently connected to the main grid are essentially part of the main grid although may have different ownership arrangements, e.g. they may be 'private wire' systems. These are not true microgrids as they are not designed to also operate in island mode.

In the case of sole ownership of the wires of both the main grid and smaller grid, e.g. by Scottish Hydro Electric Power Distribution (SHEPD) or Scottish Power Distribution (SPD) as a DNO in Scotland, the microgrid is merely a small part of the main grid. Cases such as the distribution grid on Orkney, which is run as a smart grid using an active network management scheme, exhibit many of the features of a microgrid. They are operated with the intention to be permanently connected to the rest of the main grid however (under normal circumstances).

With different ownership arrangements, the ownership boundary would normally contain some form of switches and the electricity flows across it would be metered, much the same as in Figure 2-3 above. However, in the case the small grid was disconnected from the main grid it would not run independently but be brought to a safe and dead (not live) state. A domestic property containing load and photovoltaic (PV) generation connected under the Engineering Recommendation G83 practice [1] would be a simple example of this. There are also more extensive examples of this in Scotland, which involve separately owned generation, load and wires, notably on private estate land. These are commonly termed 'private wire' systems in GB and are particularly relevant to this report.

2.5.2 Permanently isolated grids

Grids that run permanently in isolation from the main grid are commonly known as island or autonomous systems and again necessarily exhibit many of the features of a true microgrid. There are many examples of such grids in Scotland, e.g. Fair Isle, the island of Rum, the island of Eigg.

There is also quite a large body of literature about rural electrification in less developed regions of the world which uses the term microgrid but is about the development of isolated small grids to serve communities that are (too) far from the nearest main grid for cost effective interconnection, e.g. the examples mentioned in [2].

2.6 Other small grid cases

There are also cases where small grids exhibit the features of a microgrid but are not necessarily designed to operate as a microgrid. Four such cases, which are notably relevant to Scotland, are highlighted below.

2.6.1 Mainland connected Scottish islands

There are Scottish islands which normally run connected to the main grid but can be run isolated when problems occur. The Island of Lewis is an example of this. It is normally connected back to the mainland by way of a long 132kV overhead line with a 33kV subsea cable section between Skye and Harris.

If the mainland connection fails then diesel generation, i.e. at Battery Point, can be used to restart the island grid and supply its consumers (loads). Battery Point diesel generation can also be operated while Lewis is still connected to the main grid (if for example the demand outstrips the rating of the subsea cable from Skye) although other similar islands are not operated like this and the diesel generation is used purely as back-up. None are intentionally disconnected from the main grid to operate in island mode. Lewis is however very close to being a true microgrid in this sense.

2.6.2 Sites with back up generation and UPS

There are industrial and commercial sites which normally run connected to the main grid but, similar to some of the Scottish islands, contain back-up generation (commonly diesel) to supply the sites when the connection to the main grid is lost. This is quite common where security of supply is a premium, e.g. hospitals and military installations. Such sites also often contain Uninterruptible Power Supplies (UPS) which are normally battery supplied systems designed to immediately pick up and provide supply to critical elements (e.g. emergency lights, main computers, etc.) for a limited time period such as 24 hours.

2.6.3 Shetland

Shetland is another Scottish island example and is run as an island system not (currently) connected to the mainland GB main grid. It is however operated by a DNO (SHEPD) in a similar way to the main grid whereas isolated island systems are normally privately owned. Despite being an island not connected to the GB main grid, supply is available from the normal licensed suppliers. Should Shetland become connected to the mainland GB main grid as currently proposed, it will have potential to be operated as a true microgrid.

2.6.4 Private wire systems

Private wire systems have already been mentioned in Section 2.5 above. There are quite a few private wire systems in Scotland which vary in extent and in supply of energy to consumers. Many have historically grown up as part of private estates where it has been more cost effective to run a private wire system than have the local DNO extend its system. Private wire systems are however seeing a renewal of interest and these are discussed further later within this report.

2.7 Types of microgrid

The defining features of a true microgrid have been set out in Section 2.4 above along with other types of grid often termed microgrids in Section 2.5. The various technical, commercial, regulatory/legal and cost issues are explored in more detail in Section 4. Ahead of this, it is useful to expand a little on the typical types of microgrid there are. The main types are commonly classed as follows, although the literature available contains many permutations in attempting to classify microgrids.

- Commercial/industrial. This type of microgrid tends to serve large buildings or campuses, or small commercial or industrial sites where the generation and demand are located in close proximity to each other. It is quite often in an urban setting but not necessarily so. The Tohoku Fukushi University microgrid in Japan is an example of this, discussed in Section 3.2.
- Domestic/residential. This type of microgrid serves domestic consumers and will therefore tend to be multi-user, generally with a separate company running the microgrid. It can be either rural or urban. The Mannheim-Wallstadt residential microgrid in Germany is an example of this, discussed in Section 3.4. This is also an example of microgrid wires owned by the local main grid company (the DNO equivalent for Germany).
- Single user. This is where all assets are owned by one entity, which includes the demand, in an entirely private and singly owned microgrid. Examples of this would typically include on-site generation in a commercial/industrial site, e.g. Santa Rita Jail in the USA as discussed in Section 3.3.
- Multi-user. This type of microgrid is one where different ownership of assets is present, as in the Mannheim-Wallstadt microgrid.

These microgrids are discussed in the following Section 3 to provide case studies which help crystallise microgrid concepts.

3 Microgrid case studies

3.1 Introduction

This section of the report examines four operating microgrids to provide examples of the issues discussed already and to give context to the discussions. The four examples given are as follows.

- The Tohoku Fukushi University microgrid in Japan. This is a good example of an urban microgrid serving a number of consumers across a distinct commercial complex with very real demonstration of the benefits from being able to operate in island mode in terms of security of supply.
- The Santa Rita Jail microgrid in the United States of America. This is a fairly typical single user microgrid which is largely used to reduce energy bills but also to protect security of supply. It is a good example of local energy use to improve economics but also to increase renewable energy use.
- The Mannheim-Wallstadt microgrid in Germany. This is an example of a multi-user domestic microgrid which is owned and operated by the local electricity utility. It has been used to investigate stakeholder interactions as well as more technical aspects of microgrids such as islanding.
- The Centre for Alternative Technology (CAT) microgrid in Wales. This was the UK's first true microgrid, operating since 2009. As far as XE is aware, it is the only currently operating microgrid in the UK.

3.2 Tohoku Fukushi University microgrid (Japan)

3.2.1 Overview

Industrial or commercial microgrids are commonly constructed to provide high quality and secure electrical and/or thermal energy to an individual building or larger site such as a university campus or hospital. Arguably the most famous example of a commercial microgrid is the Tohoku Fukushi University microgrid [3], operating from 2004 to 2008 as a demonstration site [4] and thereafter as a fully integrated microgrid. Its 'energy centre' is shown in Figure 3-1 below.

Figure 3-1: Tohoku Fukushi microgrid (Sendai, Japan) [5]

The Tohoku-Fukushi microgrid is centred around the university campus but also extends supply to a high school and water treatment plant in a municipal area. It serves a demand of just under 1MW, has a single PCC to the main grid, and contains 950kW of generation. It is shown graphically in Figure 3-2 and in an electrical line diagram representation in Figure 3-3. Due to the level of load versus generation, demand loads are classified according to priority or importance to allow load shedding. The microgrid supports a number of buildings on the university campus and thus has a well-developed network within the university owned zone. This zone is provided with the highest classifications of power quality and security in regard to load importance. The microgrid is designed with the three key advantages a microgrid offers in mind, namely:

- Ensuring security of supply during intermittent main grid issues – reliability.
- Ensuring security of supply during infrequent but major main grid issues – resilience.
- Providing a high power quality to critical plant and equipment, i.e. within the university and hospital.

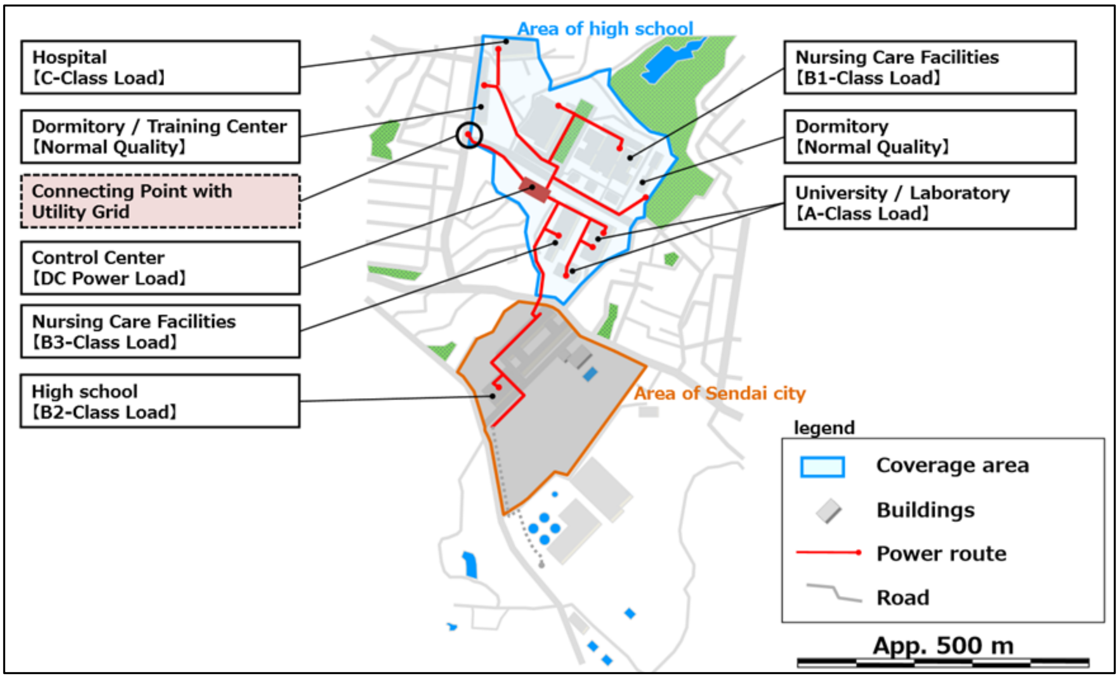

Figure 3-2: Tokyo Fukushi microgrid showing geographical layout [6]

3.2.2 Power Quality

As noted, an aim of the design of this microgrid is to provide different levels of power quality above what is generally provided by the main utility grid. The high grades of power quality (and security) (DC, A, B1 in Figure 3-3) are provided to critical systems such as the main hospital control centres and clinical machines, the lower grades (B2, B3 and normal) are connected to the local high school and other non-critical systems such as the staff living quarters. The full range of microgrid capability is summarised in Table 3-1.

Microgrid Power Quality					
Microgrid Services	**DC Power**	**AC Power**			
		A	**B1**	**B2**	**B3**
Interruption Tolerance	No Tolerance	No Tolerance	<15ms	<15ms	<15ms
Voltage Dip	Yes	Yes	Yes	Yes	Yes
Outage	Yes	Yes	Yes	Yes	No
Voltage Fluctuations	Yes	Yes	No	No	No
Voltage Harmonics	Yes	Yes	No	No	No
Voltage Unbalance	No	Yes	No	No	No
Frequency Variation	No	Yes	No	No	No
Capacity	20kW	200kVA	20kVA	600kVA	200kVA
Main Use examples	Energy Centre, e.g. Servers	Clinic (MRIs) Lab Services, Servers	Nursing Facilities, e.g. Lights	High School Lighting, Servers etc.	Nursing Facilities, Dormitories

Table 3-1 Microgrid power quality capability chart [6]

3.2.3 Security of supply

During the 2011 earthquake and following tsunami in Japan, the main electrical grid connected to this facility was seriously damaged and supply completely lost. The microgrid automatically entered island mode, fed by its three primary generation sources: 700kW micro Combined Heat and Power (CHP) gas turbines; 200kW fuel cell storage and 50KW solar PV cells. A schematic layout of the plant is shown in Figure 3-3.

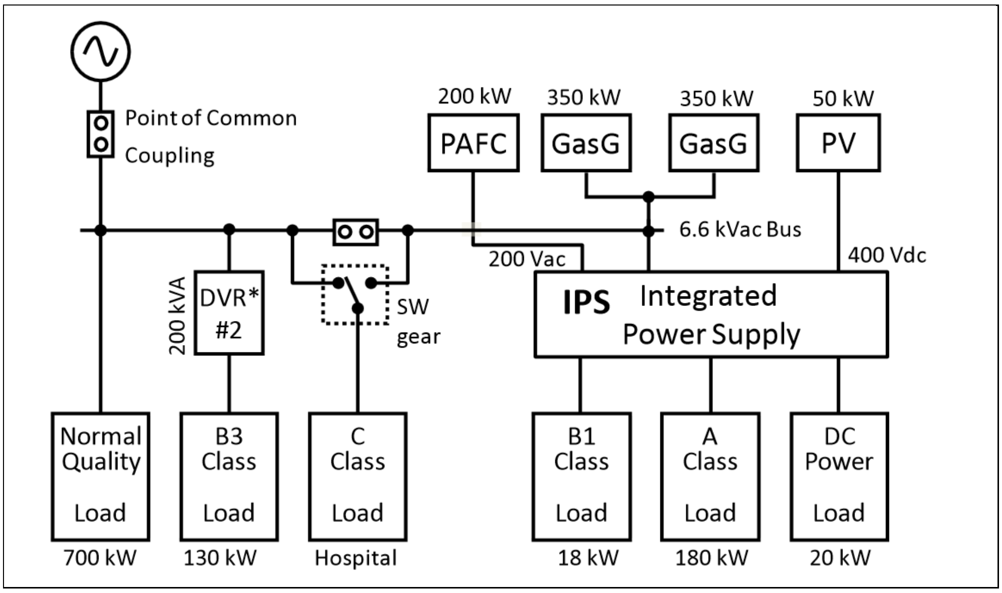

Figure 3-3: Tohoku Fukushi microgrid schematic, extracted from [6]

When the earthquake occurred, the two CHP generators were (unfortunately) affected by the abnormal conditions at the PCC and were shut down. This led to the shedding of less critical loads as per the design. The fuel cells and battery storage allowed critical loads to remain connected. The island mode operation capability enabled the university campus and attached hospital to continue functioning for two days until the main utility grid connection was re-established. The plant provided both electrical and thermal energy to the hospital throughout the disaster, allowing vital services to remain available [6, 7].

This example demonstrates the security of supply capability offered by a microgrid, over conventional centralised energy sources, particularly in locations where the utility network is susceptible to damage from environmental factors. It also demonstrates the value of suitable energy storage within a microgrid, as large disruptions at the PCC may still affect generation within the microgrid.

3.2.4 Costs

The project was proposed and carried out by NTT, Japan's largest telecom company, with initial funding from a government agency. Overall, the project developers/owners consider the costs as high and see the set up capital costs as a barrier to microgrid deployment, except where security of supply is a premium, e.g. military installations [5].

3.3 Santa Rita Jail microgrid (USA)

3.3.1 Overview

Another commercial type microgrid is the Santa Rita Jail microgrid. The Santa Rita Jail was opened in 1989 on a 0.5km^2 site in California, USA and can house up to 4,500 inmates. It has had on-site generation and some elements of a microgrid operating since 2004 but in 2012 [8] the microgrid was upgraded to include a fuel cell, PV and battery energy storage. Santa Rita Jail currently includes the following generation and storage technology.

- 1.2MW solar PV system.
- 1MW molten carbonate fuel cell power plant used as base load power in parallel with the main utility grid and on-site solar power system.
- Five 2.3kW wind turbines.
- Two 1.2MW emergency backup diesel generators.
- Advanced energy storage system (2MW - 4MWh lithium-ion battery).

The fuel cell operates as a CHP unit, meaning it provides pre-heating for domestic hot water in addition to base load electricity. The peak demand of the jail is approximately 3MW and there is one PCC to the main grid at 12kV.

Figure 3-4: Santa Rita Jail microgrid [9]

The battery and a sophisticated switch allow the jail to island and reconnect to the main grid at will, with the battery providing the source of balancing energy. The power system is controlled by a control technology embedded in the battery and switch power electronics.

Alameda County, which operates the jail, has installed a series of generation/energy resources to reduce energy consumption at the site as well as bringing forward a series of efficiency improvements to further reduce consumption. The key drivers for the microgrid are thus two-fold.

- To reduce energy imports from the main grid and hence costs of imported energy by avoiding peak demand supply costs and by supplying internally.
- To improve security of supply at the jail and hence security of the facility itself.

3.3.2 Security of supply

Before the final implementation of the full and current microgrid in 2012, the total output of the renewable generation could not meet the total full load of the system, the diesel generators were used to supplement the renewable generation during island network operation. In addition, load shedding was used in order to maintain the operation of the most critical un-interruptible load classes. In island mode (when the main grid supply had been lost) load was operated as follows.

- Loads were classified as type A, B or C, with A being the most critical.
- Type A loads were never shed and kept energised as much as possible.
- Type B loads were shed depending on the overall balance of energy (generation versus load).
- Type C loads stayed disconnected until the connection to the main grid was restored.

Loads were controlled in accordance with operation of the back-up diesel generators and in accordance with frequency control during islanding, i.e. shedding occurs for low frequency. If frequency becomes high, generation is curtailed.

Since later commissioning of the energy storage, PV and fuel cell in 2012, there is now enough renewable generation (and storage) for Santa Rita Jail to operate isolated from the main grid without recourse to the back-up diesel generators. There is still a load shedding scheme but it is much more refined. In cases where the battery energy storage is unavailable the load shedding will revert to the older ‘A-B-C’ scheme.

Prior to the microgrid installation, any outage of the utility network would result in a 10 second total loss of power in the jail prior to the backup diesel generators operating. The microgrid gives the flexibility of being able to run in island mode, and to do so seamlessly (<8ms at the PCC) when required [10]. A simplified electrical schematic of the microgrid is shown in Figure 3-6 and the geographical layout in Figure 3-5.

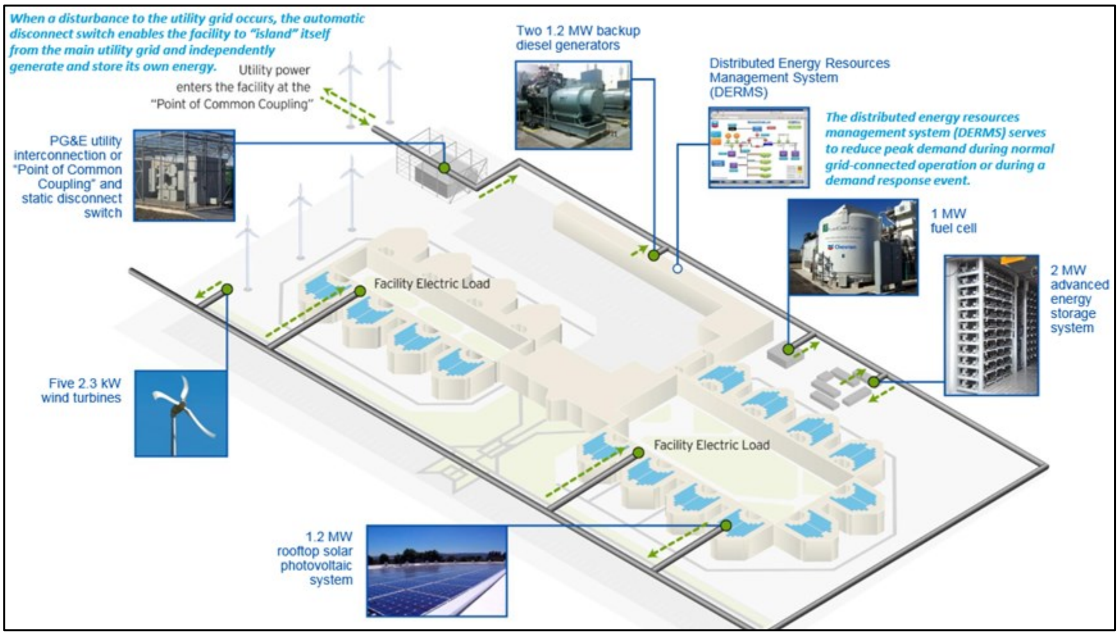

Figure 3-5: Santa Rita Jail microgrid layout [11]

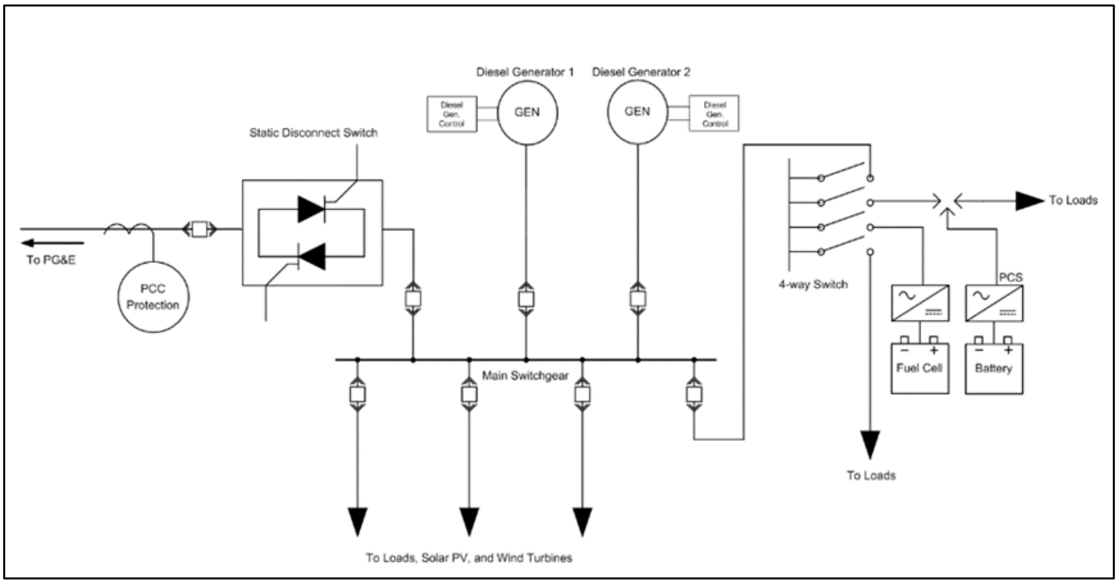

Figure 3-6 Santa Rita Jail microgrid simplified electrical network [11]

3.3.3 Energy costs

Santa Rita jail purchases electricity from the main grid under a complex tariff with various components. There is a standing charge, an 'energy units used' component based on time of use, and a maximum demand component also based on time of use. Daytime summer use constitutes peak and the PV arrays have helped offset peak usage sometimes saving $20,000 per month in summer.

With comprehensive forecasting, the use of the battery is optimised to deliver week-ahead schedules to maximise electricity import cost savings. As the on-site generation is mostly environmentally friendly, the carbon footprint of the jail is also reduced [12].

3.3.4 Costs

The cost of the microgrid has been put at $11,683,000 and substantial funding has been used as follows [8]. These costs reflect additional upgrades to the microgrid to enable smart grid operations, carried out in 2012.

- Total Project Cost $11,683,000
- Funding:
  - Department of Energy Grant $6,900,000
  - Renewable Energy Secure Communities Grant $1,983,000
  - Pacific Gas & Electric Incentive $2,500,000
  - Chevron ES Share $200,000
  - County Share $100,000

3.4 Wallstadt microgrid in Mannheim (Germany)

3.4.1 Overview

The Mannheim-Wallstadt microgrid project in Germany is a residential demonstration / test site. There are 580 households and 1,200 inhabitants involved. The microgrid was developed by MVV Energie, the state utility company, and has been in operation since 2006.

The site includes several privately owned small PV systems and one private Whispergen cogeneration unit. The microgrid operates around the residential and commercial units and loads. The total on-site load varies between 80kW and 230kW with the buildings' 60kW ventilation and 48kW boiler loads controlled. Generation and storage technology within the microgrid is as follows.

- A 4.7kW fuel cell.
- A 23.5kW solar PV system.
- A 1.2kW flywheel storage unit.
- Two CHP units rated at 9kW and 5.5kW (electrical).

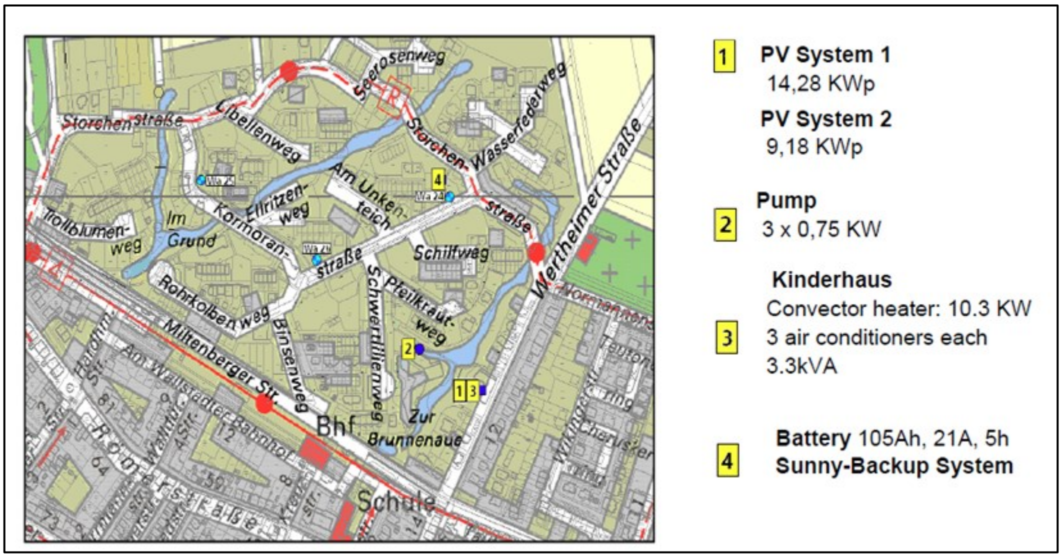

Figure 3-7: Wallstadt microgrid layout [13]

Since inception, further PV systems, bringing the total to 23.5kW, and 1 CHP system have been installed by private investors.

The main goals of the project have been to develop a true microgrid able to swiftly and smoothly switch from main grid connected mode to island mode and to let further microgrid operations and innovations be tested and operated. As well as the technical aspects, a key function is also to test and develop consumer attitudes and involvement to microgrids. The key functions are thus as follows.

- To demonstrate and test microgrid technology including islanding.
- To assess and develop community involvement and attitudes in microgrids.

3.4.2 Security of supply – islanding

MVV has successfully tested the ability of the microgrid to switch into islanding mode at Mannheim-Wallstadt Kindergarten. Frequency control has proved less than perfect although acceptable. In addition to islanding at 20kV, the Low Voltage (LV) grid has also been islanded separately to test the concept of multiple microgrids. The new LV distribution area including all relevant loads, distributed generators and storage is served by one transformer.

The MVV team also prepared the Kinderhaus to operate as a microgrid comprising two PV systems with a Sunny-Backup System, controllable loads and adding sufficiently designed battery storage as buffer, able to supply 10kW for 1 hour.

The Sunny-Backup system and its batteries (at the bottom) in the Kinderhaus

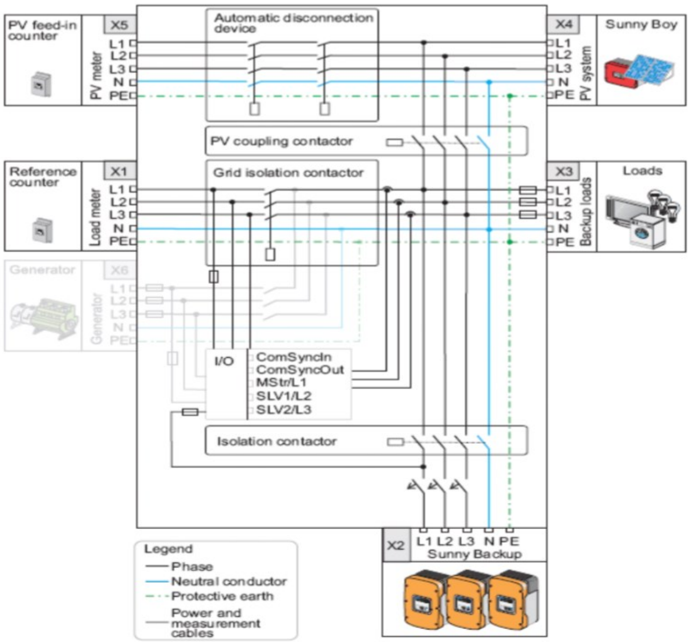

Figure 3-8: Mannheim-Wallstadt Kindergarten microgrid schematic [13]

The experiments carried out have shown that it is possible to control flexible loads (e.g. air-conditioning units) by increasing or decreasing their total consumed power according to a defined percentage of PV power virtually assigned to them [14] and hence demonstrate various control strategies for a microgrid.

Power quality and grid characteristics have been monitored in the Mannheim-Wallstadt microgrid since 2006.

3.4.3 Community involvement

As noted already, a major part of the project was in involving the community. MVV involved the community in the project through initiatives, by displaying improvements due to the microgrid and providing regular updates on the microgrid. This includes a display site with information and interactive displays for children. Members of the local community were also involved as producers and consumers of energy ("prosumers") through domestic PV. Social acceptance required more investment than expected, but has been considered indispensable to the project's success, and has demonstrated how renewable energy could be adopted by a community in Germany and help improve energy supply security [15].

An example of community involvement is one where a load shift to better match PV production was sought. To study and stimulate customer co-operation, the initiative "Washing with the Sun" was developed in 2006. During a testing period of one month, selected residents were given daily recommendations to shift consumption to times coincident with high local PV generation. Residents recorded their individual load shifts of washing machines and tumble dryers. The goal of this activity was to evaluate the ability of the residents to adapt to a demand side management strategy. The load profiles were then evaluated and showed a significant and successful load shift [13].

Figure 3-9: Mannheim-Wallstadt community information display [13]

3.4.4 Funding

The project was funded and supported by the European Union "More microgrids project", which included private investors and covered a number of different projects. The private investors comprised of major European manufacturers, power utilities, potential microgrid operators and research teams. The "More microgrids project" package had a budget of 4.68 million Euros [16] spread around the various projects.

3.5 Centre for Alternative Technology microgrid in Wales

3.5.1 Overview

Although the CAT microgrid is rurally located, it is a single user microgrid in the sense it serves the centre's premises. The site is located in Wales and has been operational since 2009. As far as XE is aware it is the only operating microgrid in the UK although one or two small test systems have been implemented and decommissioned in the meantime [17] [18]. The generation and other plant used includes the following.

- 6 x SBU-5000 inverters.
- Automatic switch box AS-Box-XL at the PCC.
- Hoppecke batteries giving 2 x 57kWh storage.
- 20kW PV, 4kW hydro, 3.5kW hydro and 600W Wind generators.

The site has a demand of 30kW and has a single PCC with the main grid. Figure 3-10 shows (clockwise from top left) the CAT centre, rooftop PV, the battery bank and metering systems.

Figure 3-10: CAT centre also showing PV panels, metering and battery banks [19]

The main aims of the microgrid are to reduce carbon emissions, demonstrate microgrid islanding and operation, to be used for courses and consultancy and to provide back-up supply during power cuts from the main grid.

- Demonstrator site for islanding/operation, used also for consultancy and training.
- To provide back-up supply during power cuts from the main grid.
- Reduction of carbon emissions.

3.5.2 Islanding from the main grid

The renewable energy produced at CAT can be fed into a battery bank and is connected together through an intelligent electronic control system along with the load through a single PCC to the main grid. During normal operation, the renewable generators provide power to all the loads and any surplus load requirement is drawn from the main grid. The batteries are not used during normal main grid connected operation.

In the event of a power failure, the CAT electricity system is isolated from the main grid via a G59 relay (see also Section 4.4.6) and operates in island mode. An electronic control system regulates the power generation according to the demand during island mode. The back-up battery also ensures that if there is no wind, sun, water or biomass it will provide power for at least 3 hours although not to the whole site demand.

After a period of time without any generation and when the energy stored in the batteries becomes low, the system will disconnect certain demand loads to ensure energy is available for the emergency lights, servers and telephone system.

3.5.3 Costs

The complete system, including the building works and generation, is understood to have cost around £5 million. CAT has suggested the cost of the microgrid control, specific wiring and batteries at around £60k with no external funding obtained. To this the generation, building works and new infrastructure build up the total.

4 Key issues of a microgrid

4.1 Introduction

This section of the report examines some of the key issues of microgrids covering out defining features, issues both problematic and useful, and costs. The discussions in this section are in part generic but where appropriate focus on GB and Scotland specific aspects such that GB national context is brought to discussions, for example around jurisdiction dependent issues such as licensing and other regulatory aspects.

This section of the report is broken down as follows.

- General technical design and operational considerations.
- Key physical components, systems or plant.
- Key electrical design aspects.
- Regulatory issues around licensing, licence exemptions, consumer rights, metering and other regulatory aspects.
- Cost considerations through lifetime.
- Other issues to consider (not expanded upon in this report).

4.2 Technical design and operational considerations

4.2.1 General

Design and operational considerations can be numerous and quite site specific. However the type of microgrid proposed, i.e. whether it is an island system, true microgrid or private wire extension to the main grid, will be a key factor.

Proposals for private wire systems which are not true microgrids and avoid island operation are technically much simpler but are relevant to the Scottish context and discussed further in Section 5.6.

4.2.2 Connection to the main grid

For the most part, if properly designed in the first instance, a microgrid when running connected to the main grid may have little to consider other than the decision as to when to disconnect and run in island mode if it is to be run as a true microgrid, e.g. if a fault occurs in the main grid affecting supply.

If part of its concept is to control power flows to or from the main grid, or within its own network, then this will also be a consideration requiring monitoring at the interface and/or within its own network together with appropriate control of generation and demand. This might be done to avoid constraints with the main grid and avoid dependency on grid reinforcements as affects much of Scotland, or to take advantage of fluctuating electricity prices and supply electricity locally. This type of control can be relatively straightforward.

4.2.3 Islanded operation

Islanded operation is much more complex and requires sufficient generation (including storage if used) to cover the demand at all times. It also requires that either or both generation and demand are flexible and controllable to the extent that they can always be matched in real time. This commonly leads to the demand loads being classified in terms of importance or priority with the lower priority loads being shed as necessary to retain control of the microgrid and ensure priority loads are kept on.

If the generation and demand are not matched, then microgrid frequency will not be controllable and this will be a problem potentially resulting in damage to equipment and shut down of the microgrid. This may dictate the extent to which the microgrid runs islanded or that energy storage is needed. This issue is avoided when connected to the main grid as the main grid sets frequency.

4.2.4 Other technical issues

Another key set of issues are those around the design and control of a microgrid in respect of other technical parameters, e.g. voltage range, voltage phase balance and voltage fluctuations, all of which should remain within acceptable ranges both within the microgrid and in respect of the main grid. These are discussed briefly in Section 4.4.

Another issue is whether the microgrid runs as an AC or DC system or utilises both and the extent to which this is a design decision or dictated by the nature of the systems involved. Most microgrids are AC and use DC for batteries and related systems.

4.3 Physical components

The physical components of a microgrid can be broken down into categories as follows.

- Generation to supply electricity.
- Demand to use electricity. This can be consumers using electricity but can also involve conversion to heat or hydrogen for example.
- Wires to transport the electricity, including underground cables, transformer and other common electrical plant as necessary.
- Interface to the main grid (PCC) including metering, switches/breakers, synchronising relay, protection and control. This is not part of a microgrid which runs only as an islanded system and only part of this equipment is needed for a private wire system running permanently connected to the main grid.
- Control systems for the process of connection and disconnection from the main grid (for a true microgrid). A private wire system which runs only when connected to the main grid will also need some control albeit relatively straightforward.
- Control systems to run in islanded mode. This is not part of a microgrid which runs as a private wire extension normally connected to the main grid.
- Other components if desired or necessary, e.g. energy storage, customer metering.

Figure 4-1 overleaf shows a microgrid using a schematic notation. It is a single PCC microgrid with a selection of controllable and non-controllable resources. The PCC is defined with a switch and across the PCC is a synchronising unit which will allow a live microgrid to reconnect with a live main grid.

The microgrid components are divided up into AC and DC systems interconnected by the wires of the microgrid. The load is divided according to priority with critical loads as those that it is desirable to maintain at all times and with lower priority load as controllable and shed-able (the lowest priority).

The generation is also divided into controllable, predictable and less predictable where controllable might be diesel generation, predictable (but intermittent) tidal stream, and (relatively) unpredictable and intermittent such as wind. Also noted is storage type generation such as dammed hydro.

Energy storage appears in both AC and DC systems but it should be noted that some forms of quoted energy storage are not two-way, i.e. thermal storage heating or thermal water heating is sometimes used as a controllable dump load but the heat is not readily recoverable, and this is different from, for example, a battery type system where the energy can be taken from or put back into the microgrid.

Overall, bar the PCC and associated switch and synchronising equipment at the interface to the main grid, the microgrid displays much the same features of any island grid but because of its ability to run both connected to the main grid and isolated from the main grid is more complex.

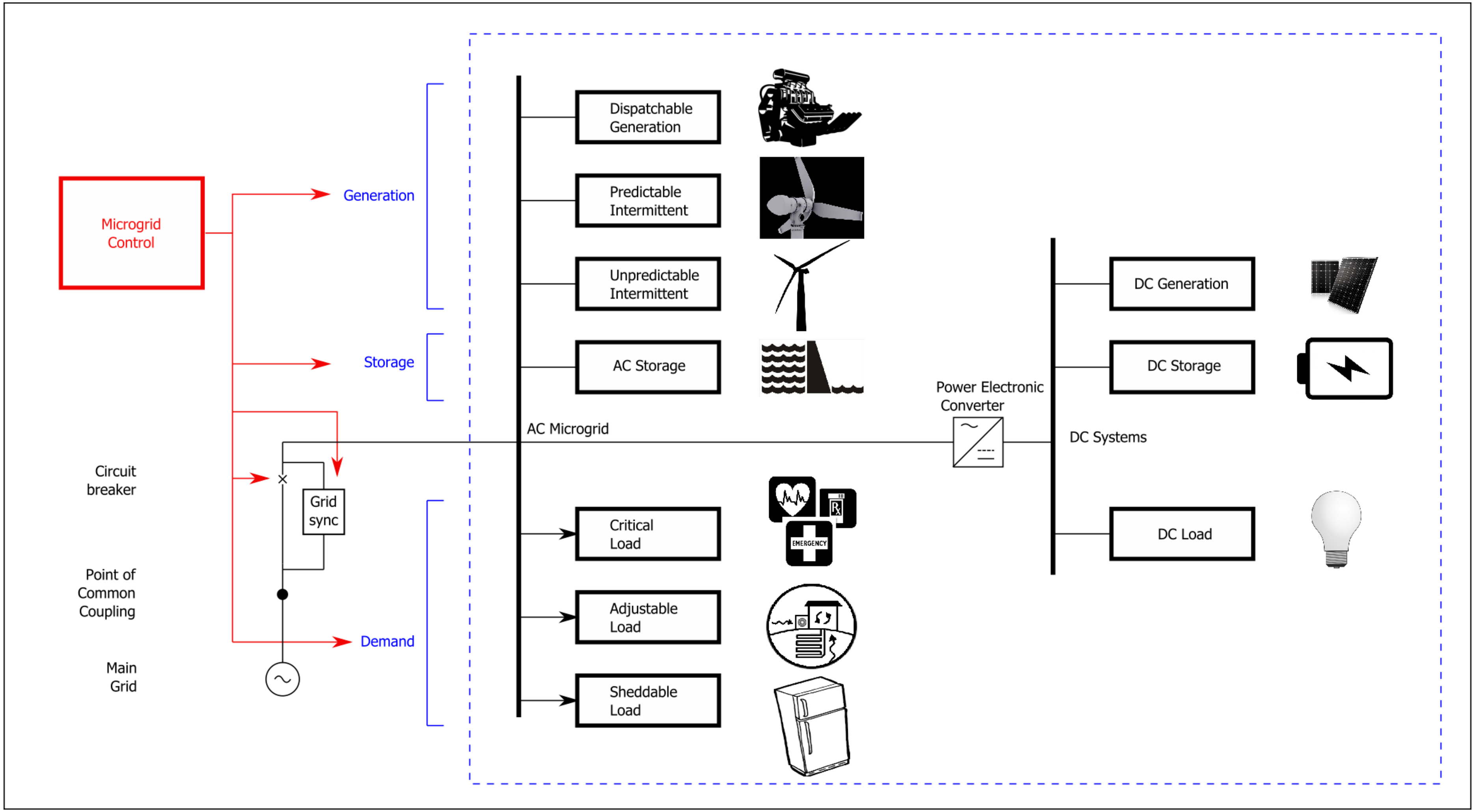

Figure 4-1: Schematic of a microgrid

4.4 Technical design issues

The technical issues of a microgrid are essentially those of any grid with the added complication that the issues need to be addressed in both running modes for a true microgrid, i.e. connected to the main grid and when running islanded. There are also technical issues to address in transitioning between the two modes. This section presents a brief overview of the technical issues that are most particular to a microgrid.

4.4.1 Frequency

When running connected to the main grid, frequency is controlled by the main grid. However, in island mode, frequency must be controlled by the microgrid. This requires a mix of controllable generation and demand. In main grids this function is traditionally provided by controllable generation but in small island systems controllable demand is commonly used also for this function. Controlling frequency requires matching the demand and generation. Frequency is the same at all points in the microgrid and hence can be controlled by any adjustable generation or demand.

The use of poorly controllable or intermittent generation such as wind and solar is a problem and the control of frequency in island mode has commonly led to the use of controllable diesel generation, storage devices and controllable demand.

4.4.2 Voltage

When running connected to the main grid, voltage will in part be controlled by the main grid and largely be defined by the main grid at the PCC. However, voltage within the microgrid will tend to be harder to control further from the PCC and if being transformed to different voltages from the PCC through fixed tap transformers.

In island mode the generation in the microgrid will largely set voltage where it is connected, but away from this voltage will be determined by the power and reactive power flows through the wires. Unlike frequency, voltage is a local variable requiring careful local control. Careful up front design of the microgrid is a key aspect in ensuring voltage is suitably controlled in operation, particularly in island mode.

4.4.3 Earthing

In the UK, medium voltage (MV) networks, e.g. 3.3kV, 6.6kV, 11kV, 20kV and 33kV, are normally earthed only at source. This means that the network is earthed only at its ‘starting point’ or supply substation on the main grid. When switching into island mode, this point of earthing is disconnected and should be replaced by a new source earth within the microgrid.

Earthing and related safety issues are also relevant to LV networks.

4.4.4 Dual supplies

In the case where a microgrid is used to supply electricity to consumers who are already connected to the main grid (or another source of electrical energy), care must be taken in respect of safety. Specific attention should be paid to isolation and earthing of the supplies and risks of inadvertent interconnection considered.

Historically, unless specific measures were taken to ensure safety, the UK Electricity Supply Regulations [20] prohibited the use of a microgrid to (privately) supply consumers if the consumers also had a separate supply from the main grid or another source. The Electricity Supply Regulations are however now superseded by the Electricity Safety, Quality and Continuity Regulations 2002 [21], which are less prescriptive over this issue which nonetheless remains to be considered.

4.4.5 Synchronisation / disconnection

Disconnection from the main grid is a relatively straightforward process but requires rapid instigation of frequency control and other control actions to keep a true microgrid running. Synchronising back to the main grid requires a synchronising relay and control of the generation or demand within the microgrid to match frequency and voltage waveforms with the main grid. Synchronising itself is a well-known process but the microgrid must have the fine control to facilitate it.

4.4.6 Interface protection G59

In the UK, G59 protection is used with sources of energy (generation) to ensure they are disconnected when the main grid forms an island within which they are contained. This is done to prevent the sources of energy (generation) continuing to supply the islanded and desynchronised part of the main grid and avoid dangerous situations to plant and people. This is the antithesis of a true microgrid which aims to keep functioning when disconnected but nonetheless must be built into its functioning. For a microgrid, the G59 protection detecting an island in the main grid would be a reason to island in itself, e.g. this is a feature of the CAT microgrid discussed in Section 3.5.

4.4.7 Other technical issues

Aside from the key issues above, there are many other technical issues related to power system design and operation that are relevant. These are however well understood and not expanded on here. Some of the other key technical issues include: protection, voltage fluctuations, harmonics, voltage unbalance, insulation coordination, transients, stability issues and fault levels to name but a few. It is essential that these are addressed to an adequate level to ensure that, as applicable to the type of microgrid being considered, compliance with main grid requirements is achieved, the microgrid itself operates within satisfactory limits, consumers are not adversely affected and microgrid generation is able to operate satisfactorily.

4.5 Technical summary

Technical aspects have been discussed in the preceding sections and whilst a not insignificant level of technical consideration in design and operation is required, there are significant differences between the three types of microgrid key to this report. Table 4-1 illustrates some of the key issues and shows that the true microgrid is the most complex. Operation in island mode is also very significant in terms of complexity whereas the private wire system connected permanently to the main grid is generally the simplest technically.

Component issues	True microgrid	Island microgrid	Private wire system
Generation	Yes	Yes	Yes
Wires	Yes	Yes	Yes
Demand / load	Yes	Yes	Yes
Main grid interface	Yes	-	Yes
Main grid synchronising	Yes	-	-
Island mode control	Yes	Yes	-
Grid connected control	Potentially	-	Potentially
Earthing control	Yes	-	-
Overall design and operational difficulty	High	Medium / High	Medium

Table 4-1: Technical highlights table

4.6 Regulatory aspects

4.6.1 Ownership

There are many ownership arrangements for microgrids from a single owner to multiple owners. It should be borne in mind that the elements that make up a microgrid constitute different types of technology, i.e. generation, demand, wires, possibly storage, and separate ownership of all these is possible. Also there can be separation of electricity supply or an independent 'system operator' role. These will in part be dictated by jurisdictional rules and regulations.

Single owner microgrids are most commonly commercial or industrial sites which are wholly contained within single owned premises. Multiple ownership microgrids are more common where there are individual consumers distinct from the generation owner or wires owner, e.g. domestic properties.

In GB, it is not normal practice for a DNO to operate its system with the intention to be able to create islanded areas. The relevant codes are designed to avoid this. For example, Engineering Recommendations G59 and G83 cover generation from the very small domestic scale upwards and specifically require generation to be disconnected should an island from the main grid be created. Microgrid type proposals tend to be private wire systems rather than DNO owned wire systems although the key drivers for this in Scotland are other matters.

For larger licensed activities, there are requirements for business separation of generation, distribution, and supply of electricity. For smaller private systems at the community level, some level of co-ownership or non-business separation is acceptable, e.g. it is acceptable for a domestic consumer to own their own PV panels and consume the electricity on their own premises. The regulations on licence exemptions include provisions around this aspect, which should be carefully considered along with the impacts of the various ownership arrangements possible on control of businesses and their operations.

4.6.2 Licences and exemptions

Licences or licence exemptions are required for generation, distribution and supply activities. This is set out in Section 4(1) of the Electricity Act 1989 [22]. All entities undertaking any generation, distribution or supply activity should be aware of this and determine whether a licence is required, whether an exemption can be applied for, or whether an exemption is applicable without application. This aspect of microgrids is probably not as well appreciated as it should be.

There are however licence exemptions available for generation, distribution, and supply of electricity and at the community level many microgrid schemes will fall within the bounds of class exemptions where an application for a licence exemption is not required [23]. This is different to exemptions for larger situations, e.g. larger generators to 100MW can be licence exempt but must apply for and obtain the exemption.

The rules governing class exemptions can be complex, do need to be checked carefully on a case by case basis and need some interpretation. The following guidelines are suitable for an initial view but should be clarified more rigorously on a project specific basis.

Generators under 10MW are eligible for a class licence exemption.

Distribution class licence exemptions are available for the following three categories.

- Small distributors - distribution of less than 2.5MW to domestic consumers.
- On-site distribution - distribution on-site to domestic consumers not exceeding 1MW.
- Distribution to non-domestic consumers - distribution that is not to domestic consumers at any time.

Supply class exemptions are more complex and eligibility should be carefully established. However, in short, class exemptions are available as follows in the following three categories.

- Small suppliers - persons which do not supply any electricity other than that they generate themselves and supply electricity not exceeding 5MW and not exceeding 2.5MW to domestic consumers.
- Resale - supply under certain conditions of resale, i.e. from another supplier.
- On-site supply - on-site supply which allows electricity generated by themselves and/or supplied by a licensed supplier and can include supply off-site by way of private wires with up to 1MW of domestic consumers.

It is worth noting that IDNO licences are available and these are less onerous than DNO licences but still have substantially more requirements than an exempted distributor. Both IDNO and DNO operate their distribution networks according to their licenses and under regulation by Ofgem.

In all licence exemption cases it is still important to be aware of the legal / regulatory obligations placed on each activity, e.g. third party supplier access [24], although the exemptions do generally relieve the exemption holders of the obligations a licence holder would have.

4.6.3 Consumer rights of choice

Consumer rights are upheld by the regulator, Ofgem, and under law a consumer has the right to choose its electricity supplier (from the GB market place). This could be a moot point in microgrids where electricity sales are priced below market retail rates and/or where consumers have other interests in the microgrid but is nonetheless noteworthy and presents an issue that microgrid developers need to be aware of.

It is noteworthy that the microgrid (private wire) distributor must facilitate this consumer right and allow access to other electricity suppliers or otherwise demonstrate that to do so would require it to increase the capacity of its distribution system and that this is not technically possible or will have an adverse economic impact on the distributor or others.

In providing 'third party' supplier access, the microgrid (private wire) distributor can levy charges for 'Use of System' on suppliers much the same as a normal licenced DNO, e.g. [25]. Charging practice must however be non-discriminatory and transparent and approval of a charging statement by Ofgem is required. It should also be noted that in providing 'third party' supplier access, the microgrid (private wire) distributor may also be required to install new elements of its distribution system to connect the consumer and this may entail cost, albeit recoverable.

For supply and metering, a third party supplier adds complication to the metering and settlement processes. With a mix of private supply and third party supply, third party consumer metering should be capable of half hourly metering which is deducted from or apportioned from metered volumes at the PCC. If all consumers on the private network opt for third party supply with various suppliers, then the system can revert to normal practice with each meter being registered – in this case there is no need for metering at the PCC.

4.6.4 Metering and commercial aspects

There will normally be metering for a microgrid (private wire) at the PCC where the interface to the licenced distribution network is. A licenced supplier will need to be appointed to supply or offtake electricity to and from the private network.

It is also conceivable that main grid interfaces could be at consumer properties creating dual supply points, although concerns over earthing, faults and safety are notable. Import and export to and from the microgrid will be via a licensed supplier and need to be considered as part of the overall financial modelling.

Within the microgrid, different consumers may be separately metered as will the generation. This allows trading of electricity within the (private wire) microgrid without recourse to the GB market with pricing which can be advantageous for consumers and the generation.

Consumer metering specifications within the private network should bear in mind consumer rights to change supplier and the issues this will bring for metering should a consumer request a third party supplier. Generator metering within the private network will need to be to relevant codes of practice.

A key point with metering is that renewable generation can claim green benefits such as the Feed-in Tariff even when being used by local demand. It can be metered at source within the microgrid (private wire) system meaning that full green benefits can be claimed despite the use of its generated electricity within the microgrid.

4.6.5 Other legal and regulatory issues

Aside from the above, there are other legal and regulatory aspects to be fully understood in the development of a microgrid. Fully understanding the legal and regulatory landscape is in itself a fairly substantial task. Some general points of note are set out below.

- **Grid connection process and requirements.**
  Connection of a microgrid to the main grid will still require formal connection application and agreement processes and the main grid owners and operators will still require visibility of the microgrid and all its components, including the generation. As noted in Section 5.6 this may mean that constraint issues or other problems in the main grid are not circumvented.

- **New connections.**
  A DNO is licence obliged to offer connection to any new customers. This includes both generators and demand side consumers. A private wire microgrid is not subject to these exact same licence requirements but it is nonetheless a situation that could arise and need to be dealt with sensitively. This situation might also arise where a local consumer serves a notice requesting access via a 'third party supplier'.

- **End of lifetime.**
  The obligations that the microgrid will have at the end of its lifetime – a normal DNO would be obliged to undertake asset replacement and refurbishment to ensure continued supply to its customers.

- **Other regulatory issues.**
  There are other regulatory issues to consider even for licence exempt cases and, if nothing else, it is pertinent that an unlicensed exempt case is aware of the broad raft of obligations a licenced party has, e.g. terms and conditions for distribution service, standards of conduct, service quality standards, customer information provision and billing and termination procedures.

4.7 Costs

4.7.1 General

To date, costs for true microgrids are generally considered to be an issue with most being considered relatively expensive and having necessarily been supported by public sector grants and loans. This is shown by the case studies in Section 3 although the CAT microgrid appears to have been realised at reasonable cost. There is however cost uncertainty over what is actually included in many quoted costs which include the costs of generators as well as the microgrid infrastructure itself and, whilst costs are a notable issue, the wider question of value and returns is more important.

Costs cover a wide ranging set of categories, cannot be quantified easily in general terms as they are quite site specific, but can be broken down according to lifecycle as follows.

- Development costs.
- Capital set up costs (which can subsume the development costs).
- Operation and Maintenance (O&M).
- Decommissioning or end of lifetime costs.

XE has provided ballpark guidance on costs that might be expected for each phase of a typical microgrid in Section 4.7.6. The cost ranges are wide as microgrid schemes themselves vary very significantly. Ahead of this, the following subsections discuss costs through the project lifecycle.

4.7.2 Development costs

Development costs need to include all design, permitting and leasing, consenting, legal, financing, surveying and testing costs to take an idea of the microgrid from concept to the point that it is fully understood, consented, and ready to be implemented.

4.7.3 Capital set up costs

The set up costs are primarily for the procurement, installation, testing and commissioning of the microgrid and its associated systems. This will normally be the major cost as it will include generation, private wires, control, demand supply and metering systems. Added into this are the business set up costs although these may have been undertaken as part of the development costs.

Also relevant are any costs from the main grid which may include works at the interface and/or paperwork costs. At medium voltage, these costs can be significant, e.g. £50k to £100k plus at 11kV.

In addition, a true microgrid will have costs over and above a private wire system permanently connected to the main grid for its control and communication systems and interface works.

Capital costs are likely to be notably higher where two-way energy storage is used (e.g. battery storage) but may be more efficient where one-way thermal energy storage is used, e.g. water heating.

Capital costs are also likely to be higher where new private wires are to be run over longer distances. Conversely, costs may be more efficient if the new private wires are required in any case, e.g. as part of a new residential development, or are related to a restricted geographical area such as on-site.

Costs also increase with voltage so smaller microgrids using LV distribution (which must be restricted geographically to work) are likely to be more cost efficient than those using higher voltage levels such as 11kV and covering longer distances.

4.7.4 Operation and Maintenance

All items within the microgrid will incur O&M costs from the generation, through to the wires and including equipment at consumer premises and the interface.

There will be a typical O&M figure (usually a small percentage of the capital asset costs on an annual basis) probably involving a third party service contractor for the O&M activity. In maintaining a microgrid and its constituent parts there should be a maintenance plan to regularly inspect, test and periodically replace near end of lifetime parts and consumables. More difficult to assess is the risk of a major failure which might result in both major cost expenditure and downtime to all or part of the microgrid – an inherent risk taken in owning such assets. There are of course warranty periods (typically 1-2 years for electrical plant and up to 5 years for plant such as wind turbines) and insurance which may assist.

To ensure the long term success of a microgrid, it is important that the system is fit for purpose, and availability is maintained at a high level throughout the project's life cycle. Thus it follows that initial design and O&M strategies must be well planned and executed in order to keep the system operating as intended. In order to have well planned and executed O&M strategies the appropriate funding must be available from whichever financial model is applied to the project.

Other operational costs will include the running of the various business entities, including operations, staff costs, insurance, legal and professional costs, profit etc.

There will be costs associated with the interface to the main grid and GB electricity market for buying and selling electricity.

Finally, there may also be operational costs associated with controlling the microgrid, particularly if an island mode is used. These costs may include generation curtailment (e.g. to match demand), demand side control and consideration of microgrid system losses.

4.7.5 Decommissioning (end of lifetime)

Not necessarily at the forefront of thinking, but nonetheless something that must be considered in the business model, is the end of lifetime expectations and what will happen next. Much grid related plant is designed for a 40-year lifetime, but at this point major system replacement and refurbishment would be a notable cost. Alternatively, the microgrid could be decommissioned (at cost). For microgrids facilitating generation such as wind, there may be a mismatch of asset lifetimes, e.g. wind turbines are commonly designed to around 20 years. Either way, consideration needs to be given as to what happens next with all the constituent parts and participants in the microgrid scheme.

4.7.6 Ballpark cost guidance

As already noted, it is difficult to provide clear guidance on costs as they will very much depend on the specifics of the microgrid. Table 4-2 provides a rough order of magnitude to XE's cost expectations with ranges based on typical community scale schemes.

Lifetime phase	Ballpark cost	Comments
Development	£0.1M - £1M	Depends on extent of microgrid, degree of environmental and consenting required and inclusions in development costs.
Capital set-up	£0.1M - £5M	Will depend on voltage, distances involved and whether generation and energy storage is included in costs. The lower end of this range would apply to an LV microgrid over a restricted area with small generators and low cost technology. The upper end of this range could apply to a medium voltage (and LV) microgrid spanning several km, with relatively large generators (500kW – 1MW) and more expensive technology such as batteries.
Operation and Maintenance	2% - 10%	As a percentage of capital set-up costs. Large main grids typically take general O&M at around 1-5% but small systems can be more variable. Some microgrid components may be more O&M intensive than the basic grid components. This cost estimate does not include energy costs. It is for the general O&M activity only.
End of lifetime replacement or Decommissioning	£0.1M - £5M	Expected to be similar to initial capital set-up costs minus some saving for reuse plus some extra cost for decommissioning then replacement.
	10%	As a percentage of capital set-up for asset removal, recycling and disposal.

Table 4-2: Ballpark cost quantification for a community microgrid

4.8 Other issues

As noted elsewhere in this report, there are other issues to consider beyond the scope of this work. Therefore, microgrid stakeholders should also consider issues such as:

- Financial modelling
- Sources of funding
- Electricity and heat pricing
- The use of heat networks, e.g. district heating
- The use of other energy carriers, e.g. hydrogen
- Environmental factors such as the impact of the microgrid on the local environment and its wider impact, e.g. on carbon emissions
- Consenting aspects of the microgrid
- Legal issues
- Business arrangements
- Insurances

5 Microgrids in the HIE region and Scottish context

5.1 Introduction

This section draws on the discussions to date to put microgrids firmly into context in both a Scottish context and with reference to the Highlands and Islands. The aim of this section of the report is to draw together the key aspects of a 'Scottish microgrid', what additional issues there are, why microgrids are or may be of interest, and what pros and cons there are to them.

Throughout the preceding sections, Scottish or British examples have been given and general context has been provided, particularly around regulatory aspects which are country specific. Some international examples have also been discussed in Section 3.

5.2 Key Scottish issues

As already noted, Scotland already contains many examples of purely island grids, e.g. Fair Isle and Shetland, many private wire systems and examples of back up supply schemes on the main grid, e.g. Lewis.

In relation to the grid aspects, there are perhaps two key current issues for community schemes in Scotland which have driven interest in microgrids. These are constraint problems on the main grid and issues around licensed supply or transfer of electricity over the main grid when there is a desire for a local electricity exchange.

Constraints on the main grid in particular have been driving interest away from the traditional model of grid connection for a community renewable energy scheme, of which microgrid proposals are one manifestation in trying to overcome constraint issues.

The issues around supply are also a factor but are less clear to many. There is clearly a thirst for local supply arrangements and whilst private supply can offer a solution in this area, this is very much a developing front. There are also other issues involved in the value chain here such as using locally supplied electricity to reduce fuel costs for heating and transport, reduction of greenhouse gas emissions and other pollutants through a change to renewable energy sources, local business creation and local economic uplift.

Finally, as many schemes are currently reliant on Feed-in Tariff credits which are gradually diminishing, there is an urgency in that the financial benefits of schemes are reducing over time and waiting for grid constraints to be removed is not an attractive option.

In explaining how microgrid type proposals can offer some advantage in these matters it is useful first to understand the traditional business model for the development of a renewable energy scheme, which in many cases is the starting point from which microgrid proposals have been developed to overcome problematic issues.

5.3 Community renewable energy and the grid – traditional model

Before exploring key drivers in Scotland for microgrid proposals in more detail it is useful to understand the traditional model in relation to a community renewable energy scheme. In terms of grid and the sale / use of the generated electricity, such schemes are similar to larger scale commercial developments. A renewable energy scheme is developed, consented, financed and built. For communities there is commonly a heavy involvement and a level of ownership also. The renewable energy scheme is then directly connected to the main grid with its electricity sold to a licensed supplier and any green credits (e.g. Renewable Obligation Certificates or Feed-in Tariff pricing) realised. The community benefits financially by way of ownership (sale of electricity) or other arrangements.

This model is shown in Figure 5-1, which illustrates that the flows of electricity may be at a local level albeit via the main grid, but the flow of money is via the GB market.

There are many examples of this approach, e.g. Horshader Wind Turbine on Lewis. The advantages are that it is a clean and simple, well established and understood, and ultimately deliverable business model with profits generally reinvested back into the community.

The key disadvantages of this model are if the main grid is constrained and cannot accept the generation export and that the community does not benefit through direct supply of the green electricity but continues to need to buy from traditional licensed suppliers at retail prices.

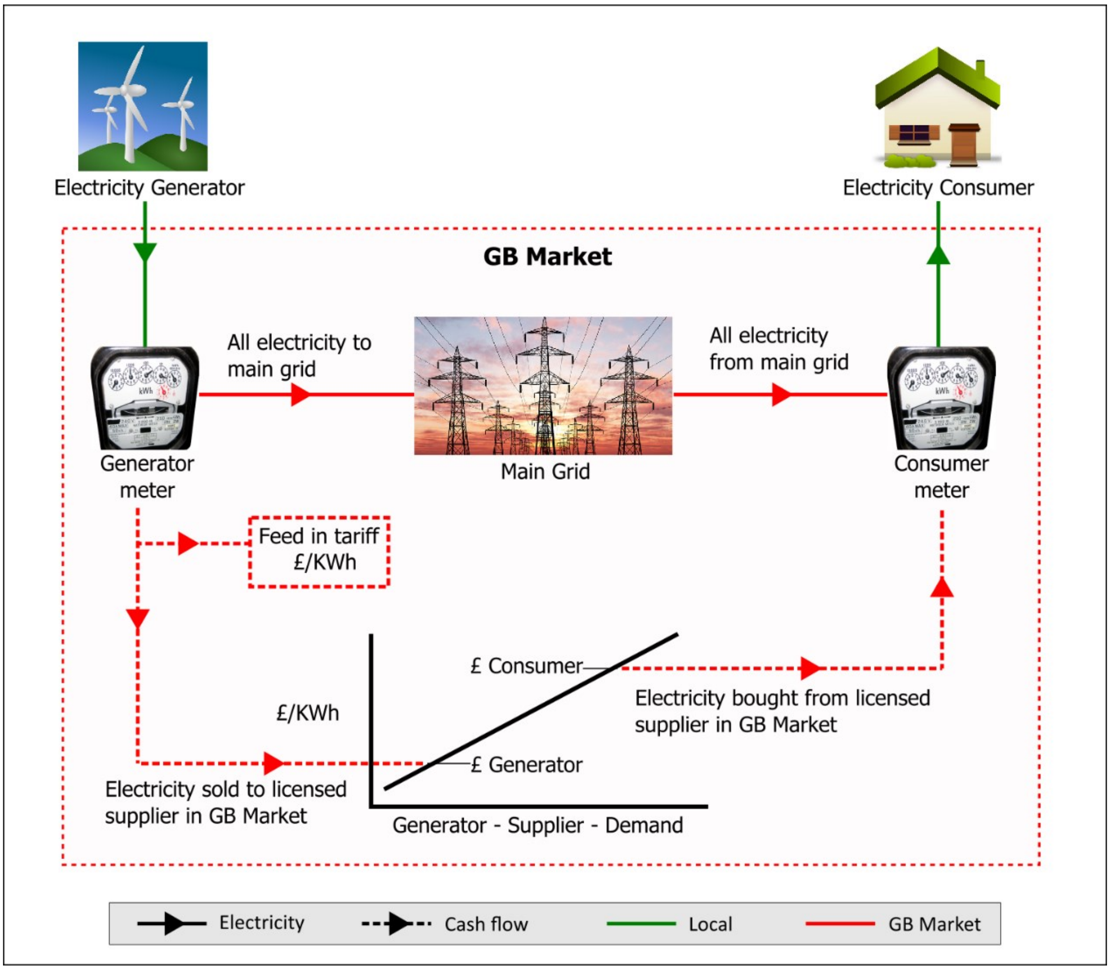

Figure 5-1: Traditional model for community renewable energy grid connection

5.4 Main grid constraints on generation export

Constraints on the Scottish transmission system are well known and understood. There are also constraints on many parts of the distribution system. Figure 5-2 shows Grid Supply Point constraints in the SHEPD region, a Grid Supply Point is the substation interface between transmission and distribution. It shows (in red) that all are constrained, illustrating the scale of restrictions with the main grid.

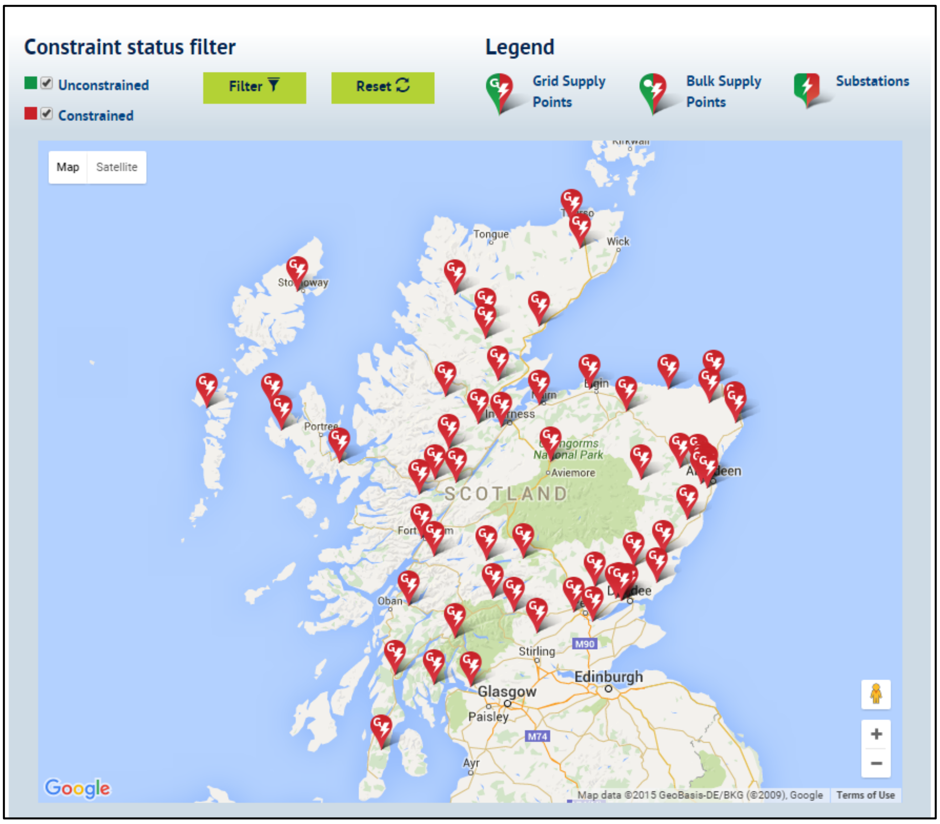

Figure 5-2: Constrained Grid Supply Points in the SHEPD region [26]

The high costs or long timescales in alleviating main grid constraints have proved to be, and are continuing to be, a barrier to grid connection of renewable energy projects for many communities in Scotland. There are a number of ways these constraints can be mitigated, normally at some cost. Some examples include the following.

- Reinforcing the main grid. This is the traditional method undertaken by the grid owners but often involves very high costs and long delays.
- Downsizing the generation (cost of lost generation and loss of economies of scale).
- Operating the generation in a constraint scheme (cost of scheme and lost generation). Such schemes are often termed Active Network Management (ANM) or 'Smart Grids'. Orkney is a well-known example.

Often however, the above are either not possible or not financially attractive. Another option is to 'soak up' excess generation locally thereby restricting electricity flows to the main grid. This can be achieved via a microgrid or private wire system. In essence, the export generation flow to the main grid at the PCC is controlled by using the local demand to whatever limit is necessary. This model is shown in Figure 5-3.

5.5 The main grid and licenced supply

Use of the main grid requires engagement with regulated and licensed entities, notably licensed suppliers which purchase generated energy and sell it back to consumers. The licensed supply model currently in use for GB (and hence Scotland) is based on the principle that a consumer can purchase energy from a choice of suppliers who compete in a competitive market. The market is designed such that suppliers can purchase energy from any generator in GB and supply to any consumer in GB.

Participation in the existing GB supply market as an electricity supplier is generally suited to larger businesses due to its complexities and costs and presents two key issues to community energy schemes that wish to trade electricity at a local level.

- Use of the main grid requires licensed supply even if seeking to trade locally. It is overly complicated and expensive to become a (small) licensed supplier, even with schemes such as 'Licence Lite' [27], which provides some relief for smaller suppliers.
- Selling energy generated by a community owned renewable generation scheme to a licensed supplier and then separately purchasing energy back as consumers is financially unattractive and is at a loss on a unit for unit basis (green benefits excluded).

The unfortunate element of the GB-wide electrical energy market is that it does little to recognise local transfers of energy which avoid much of the use of the main grid and GB market and its costs.

To try to overcome some of these issues, many new models of supply are starting to emerge (so called Non Traditional Business Models, recently consulted on by the electricity market regulator Ofgem [28]). A private wire microgrid model is one such option where energy is (at least in part) transferred from generation to demand directly and privately without being exported to the main grid and hence needing to be sold to and purchased from a licensed supplier. This is discussed further in the following Section 5.6.

Support schemes such as Renewable Obligation Certificates and the Feed-in Tariff allow separation of the sale of electricity from the realisation of the associated green benefits. This means that the green benefits can be obtained under a wide variety of situations including connection within private wire systems.

5.6 Private wire supply

5.6.1 General

As noted above, the use of a private wire system can assist in avoiding problems due to main grid constraints and facilitate the local supply of electricity. For any import into or export out of the private wire system a licensed supplier is required. For private wire systems a company is normally formed to manage the energy supply. The company business model can be formed on various bases such as non-profit, community share-holding or more commercial arrangements. A supply licence exemption would normally be required except where a scheme qualifies for a class exemption as explained in Section 4.6.2.

5.6.2 Benefits of local supply

The key benefits can be recognised as follows and are illustrated below in Figure 5-3, which also highlights main grid constraint avoidance.

- Direct and private supply cutting out the costs of the main grid and GB market can provide a higher price for electricity to a generator and a lower price for consumers. This encapsulates the concept of local supply financially.
- Although the main grid and GB electricity market will still be used, e.g. in a top up and spill manner, this is reduced and hence costs are reduced.

There are also other benefits that can be realised, for example through the use of half hourly metering at the PCC and in reductions in use of system charges related to the main grid.

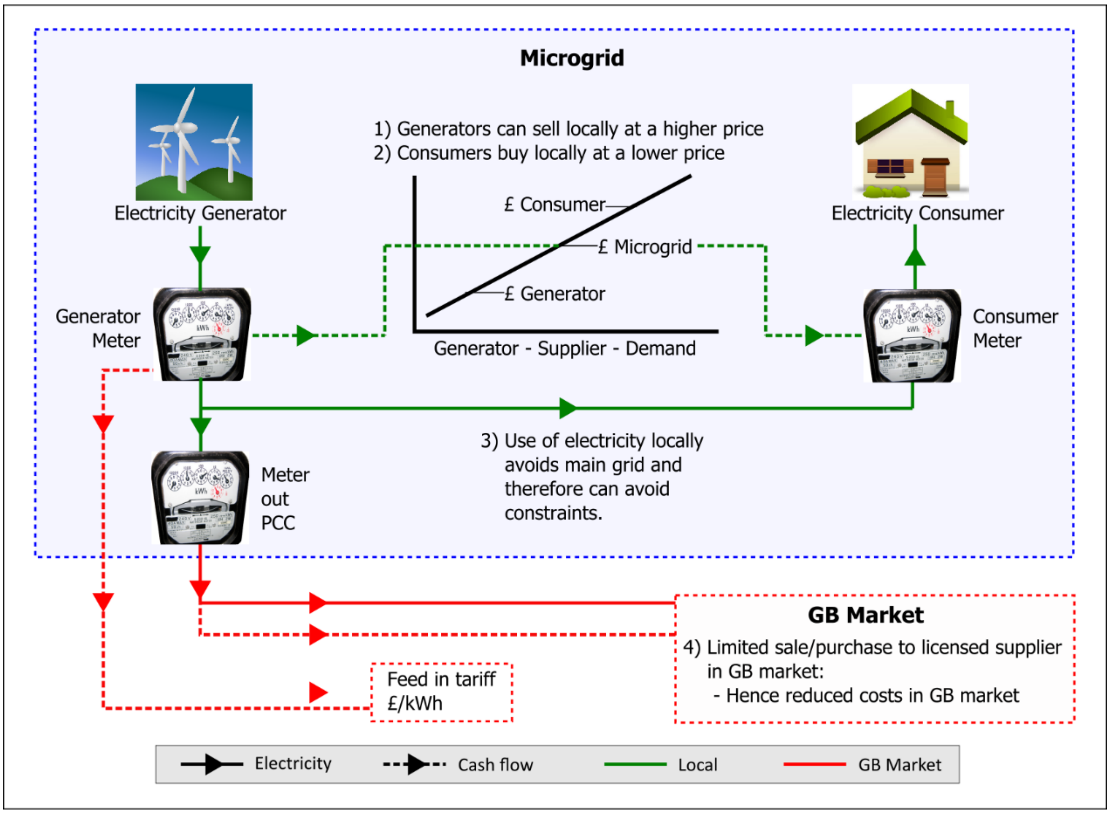

Figure 5-3: Private wire (microgrid) business model of grid connection

5.6.3 Disadvantages and issues of local supply

Some potential disadvantages are as follows.

- Embedded benefits.

  There can be a loss of embedded benefits accrual to the generation as its export contribution at distribution level to the main grid is reduced, i.e. its contribution to reducing the demands on the GB grid to supply consumers is not recognised.

- Private wire costs.

  Costs to install, operate and maintain the private wire system, including the controls for generation and demand will be higher than in the traditional model and need to be shown to still be acceptable and leading to an overall positive financial model.

- Added responsibilities, liabilities and other risks.

  This not only includes O&M costs but also end of lifetime asset replacement or decommissioning costs, costs for major failures, business costs and other liabilities such as in a health and safety related accident.

- Demand shifting and net impact on the main grid.

  There is also a question as to whether demand may have been shifted from the main grid system to the private wire system thus questioning the integrity of a 'reduced export' to the main grid. For example, providing privately supplied low cost heating may offload electric heating normally supplied via the main grid. In reality this 'demand reduction' is the same as generation and its net impact on the main grid the same.

- Demonstrable and real added value.

  There is also a question as to whether demand for electricity on the private wire system needs to be created and whether any creation is real and represents a benefit, e.g. through provision of low cost heat replacing more expensive oil fired heating. Questions such as "does the introduction of an electric vehicle and charging point bring a quantifiable benefit?" or "does the provision of lower cost electricity from a private wire system make all the difference for new business creation or would the viability be similar without the private wire, i.e. why is the business not there already?" may be difficult to answer. The creation of added value locally needs to be credible and not manufactured.

5.7 Other drivers and potential advantages of microgrids

Alongside the main driver for communities to consider microgrids, i.e. main grid constraints and the potential financial benefits of local electricity supply, there are other factors that can both drive and add value to microgrids.

5.7.1 Feed-in tariff degression

Many renewable energy schemes are dependent on a financial uplift to their energy production from support mechanisms such as the Feed-in Tariff. As the tariffs are decreasing year on year and may indeed end for some technologies such as onshore wind, there is an urgency brought to projects. As already noted in Section 5.4, many constraints on the main grid will be removed within a few years but due to the urgency around Feed-in Tariff degression, waiting is not considered an option. Hence projects are looking at alternatives to the traditional model of grid connecting a renewable energy project, including microgrids.

5.7.2 Fuel costs – transport and heating

Use of locally sourced electricity, potentially at competitive rates, can be attractive in displacing other fuel sources where costs are significant. Good examples of this are in transport and heating.

In transport, electric vehicles are coming to market and attract incentives. Transport is a major consideration for rural communities and transport (fuel) costs can be significant. Therefore, if electricity is to be used locally (or needs to be used locally) and can be available at a competitive price, electrified transport can offer a solution.

In heating, domestic space and water heating is a major consideration where rural communities may be reliant on relatively expensive fuels such as oil, coal and bottled gas. As with transport, competitively priced electricity can offer a good alternative.

In addition to the fuel cost savings, use of electricity from local renewables also brings environmental benefits in reducing carbon emissions and other pollution. Both heating and transport options also offer a degree of flexibility in how and when they are used, flexibility in demand being an essential part of microgrids.

5.7.3 Added value

As noted already, main grid constraints are a key driving factor for microgrid proposals in Scotland. However, it is good practice to seek added value from any microgrid development. Displacing fossil fuels is one area of added value, as noted above, but others such as assistance in generating new business, or providing community funds for other developments, all add value.

6 Microgrid value

6.1 Introduction

This section of the report examines the advantages and disadvantages of microgrids in the Scottish context drawing out key points to consider when evaluating whether a microgrid is a good option and will offer value rather than cost.

There are many advantages quoted in favour of microgrids. Rarely set out however are the disadvantages. In addition, many commonly quoted advantages are somewhat simplistic and need to be set in context, e.g. promotion of renewable generation sources is frequently quoted as a key advantage but this has relatively little to do with the microgrid itself and many other business models also fulfil this aim, some of which may be simpler, e.g. refer to community renewable energy schemes discussed in Section 5.3.

XE has therefore divided the summary discussion of advantages and disadvantages into the following categories, which start with questions over the defining points of a true microgrid to ascertain if this is worth considering, before moving on to consider the pros and cons of a private wire system which would cover the bulk of cases, before closing out on more general issues. Stand-alone island microgrids are not specifically addressed as island systems tend to be borne of necessity rather than choice unlike true microgrids or private wire extension microgrids from the main grid. Many island system concerns are however similar.

- **True microgrid specific** - directly resulting from the true microgrid concept of being able to connect and disconnect from the main grid and run in island mode. These aspects, e.g. increased resilience and security of supply against main grid faults, are not common with other types of microgrid.
- **Private wire specific** – resulting from the use of a private wire system as part of a microgrid concept and particularly relevant in the Scottish context. These aspects can apply to different microgrid types (true microgrid, private wire extension or island system) either in full or in part, e.g. local supply of energy 'under the meter'.
- **General issues** - issues that are not necessarily unique to microgrids or easy to quantify but are worthy of consideration, e.g. socio-economic impacts and promotion of renewable energy.

6.2 True microgrid specific advantages

These arise directly from the key defining feature of a true microgrid, i.e. its ability to run both connected to or in isolation from the main grid.

6.2.1 Security of supply – reliability and resilience

Reliability problems in the main grid such as faults which lead to a loss of supply can be mitigated by microgrids by their ability to disconnect and operate in island mode during such times. This can significantly improve commonly used metrics such as 'customer minutes lost' and ensure continuity of supply to communities. Resilience is very similar to the concept of improving reliability but is normally taken in the context of more significant duration supply losses due to relatively low probability events. Such events would typically arise from extreme weather, floods, earthquakes or major main grid problems such as substation fires or submarine cable failures.

The value of this advantage largely depends on how prone to supply loss a community is, how critical the demand is, and whether alternatives are available, e.g. via back-up diesel generation. Whilst remote rural and island communities may be more prone to supply loss (although in Scotland this may still be relatively small compared to many regions of the world), alternative back-up solutions are either already in place or relatively cost effective to deploy. More recently, concerns over security of supply at a national level have become prominent and this is also worthy of consideration.

6.2.2 Power quality

The quality of power provided can vary in both urban and rural contexts with common issues being phase voltage unbalance, excess voltage range, voltage fluctuations and harmonics. Equipment installed on a microgrid can assist in improving these and should the power quality being received from the main grid become intolerable then a microgrid can disconnect and operate in isolation.

The value of this advantage largely depends on similar criteria to those of security of supply, i.e. how prone to poor power quality a community is, how critical (or sensitive) the demand is and whether alternatives are available. Remote rural and island communities will tend to be more prone to voltage issues whereas in urban areas or on commercial / industrial sites harmonics are more likely to be problematic. Demand such as hospitals will be sensitive but so will certain other consumers. Solutions are available to correct voltage issues on the main grid (e.g. voltage boosters, load rebalancing) and also are available at low voltages with the consumer, but these would normally be used on a site-by-site basis and typically for critical demand such as hospitals.

<table>
<tr><th>Advantage</th><th>Value aspects to be considered</th></tr>
<tr><td>Improved security of supply – reliability and resilience</td><td rowspan="2">Value depends on:
Extent of issue (with main grid).
Criticality of demand (supply continuity).
Availability and cost benefits of alternatives.</td></tr>
<tr><td>Improved power quality</td></tr>
</table>

Table 6-1: Key true microgrid advantages and value questions

6.3 True microgrid specific disadvantages

As with the advantages, the disadvantages of a true microgrid result from the key features in its ability to run connected to or disconnected from the main grid.

6.3.1 Main grid interface

The interface of a microgrid to a main grid will require various plant and would normally require some form of housing or substation. There will normally be a need to provide switchgear, metering, protection, control and communication facilities, partly duplicated and split between different owners in the case of a private wire or separately owned microgrid. Whilst disconnection from the main grid can be relatively straightforward, reconnection will require synchronisation equipment and associated controls if the microgrid reconnects live. The interface adds complication and cost, which will largely depend on the interface voltage.

6.3.2 Microgrid control – islanded operation

When the microgrid operates in island mode there is a need for additional control to ensure a balance of demand and generation and that all parameters of the microgrid are within acceptable limits (e.g. frequency, voltage etc). This control mode is different to the case where the microgrid is connected to the main grid and there is a requirement for both modes.

The control systems themselves add cost, but the control actions also should be considered in this context. For example, if frequency is at least in part controlled by local renewable generation then some of this generation will be lost in performing this function. Similarly, demand may be increased or decreased (shed) outwith consumer requirements or storage devices might be necessary. Other parameters such as voltage and reactive power also need control and can constrain the functioning of the microgrid.

<table>
<tr><th>Disadvantage</th><th>Cost aspects to be considered</th></tr>
<tr><td>Interface equipment</td><td rowspan="2">Some additional complexity and cost.
Costs depend on:
Additional equipment costs.
Costs of generation losses/control actions.
Costs of demand losses/control actions.
Costs of energy storage (if any).</td></tr>
<tr><td>Control in island mode</td></tr>
</table>

Table 6-2: Key true microgrid disadvantages and cost questions

6.4 Private wire advantages

Setting aside the defining features of a true microgrid there are advantages to a small private wire system in the Scottish context, noting that at present any microgrid type is likely to be a private wire development.

6.4.1 Constraint avoidance

As discussed, electricity demand in a private wire system can be used to soak up excess generation and circumvent not being able to connect new renewable generation directly to the main grid. This has been discussed at some length in Section 5. Key questions here relate to whether more appropriate alternatives exist and what the best overall solution is. Other important issues are how long the main grid constraint will be in place for, if reinforcements are planned and whether it might be relieved faster than expected, e.g. if contracted generators driving the constraint fall away. As many constraints are temporary, investment in a private wire system to avoid them may only be temporarily needed.

6.4.2 Local electricity supply (GB market cost avoidance)

As discussed, the use of a private wire system can facilitate direct trades of electricity both physically and financially between local generators and consumers, often with connected interests. This can encapsulate the local energy concept by maximising benefits to the local community. As well as local supply of renewable energy, avoidance of the GB market for electricity means cost advantages can be realised providing lower cost locally produced green energy. The generator can also be well placed to continue to receive full green credits through whichever system is relevant, e.g. Feed-in Tariff, and potentially obtain a better price for its electricity than via a licensed supplier. The main value questions with this relate to the costs of the private wire system and the regulatory complexity that must be navigated.

Advantage	Value aspects to be considered
Main grid constraint avoidance	• Value depends on: ○ Extent of issue (with main grid) – magnitude of constraint and its duration. ○ The cost of constraint. ○ Availability and cost benefits of alternatives to a private wire system, e.g. energy storage, generator downsizing, waiting.
Local supply of green electricity	• Value depends on: ○ Consumer and generation energy cost benefit uplift set against lifecycle cost of private wire system and regulatory complexity. ○ Availability of alternatives. ○ Added value achieved, e.g. via heat.

Table 6-3: Key private wire advantages and value questions

6.5 Private wire disadvantages

The key disadvantages of a private wire system are mainly in the costs and complexities of the private wire system itself.

6.5.1 Running private wires - costs

There is a cost to the private wire system itself through design, installation, operation and end of lifetime. In particular, the costs of actually installing the private wire system may be significant. These costs are likely to be higher if the private wires are to be installed where there is already a distribution system (as opposed to a new development where new wires need to be run in any case), where the private wires run off-site and over geographically disperse customers (as opposed to a 'tight knit' on-site system), and where the voltage needs to be elevated to medium or high voltage (e.g. 11kV) rather than be at LV. It should also be noted that there may be additional control costs to consider and these may include lost generation costs and costs to consumers.

6.5.2 Technical challenges – design and operation

Technical challenges are reduced significantly in moving from a true microgrid to a private wire system as islanding aspects do not need to be considered. However, design and operation of a private wire system still requires a relatively high level of technical competence and cost, especially where it operates over different voltages, longer distances and where the generation is less controllable.

6.5.3 Regulatory and legal complexity

Complexity on the regulatory side can cover many aspects but will certainly involve consideration of ownership and business operations to remain legal, will necessarily involve licensing and exemptions and will need to consider the additional liabilities that a private wire system will involve (e.g. health and safety, consumer choice).

<table>
<tr><th>Disadvantage</th><th>Cost aspects to be considered</th></tr>
<tr><td>Private wire costs</td><td rowspan="2">• Cost increases with:
o Distance, voltage and voltage range, and whether the wires duplicate an existing system or are needed for other purposes anyway.
o Technical complexity.</td></tr>
<tr><td>Technical challenges</td></tr>
<tr><td>Regulatory costs and complexity</td><td>• Cost increases with:
o Complexity in understanding regulations.
o Additional responsibilities and liabilities.</td></tr>
</table>

Table 6-4: Key private wire disadvantages and cost questions

6.6 General potential advantages

There are many issues that can fall within this category of which many are common with non-microgrid business models and may not be easily quantifiable. The list below is extracted from a wide variety of sources for general information and consideration.

Issue	Comments
Promotion of renewable energy	There are many business models for this from which a microgrid needs to present a clear case.
Carbon reduction	This can be assessed based on available value metrics, e.g. used by Scottish Government.
Increased demand	The implementation of a scheme may create new demand which needs to be shown to be genuine and bring benefits locally.
Local integration of thermal energy	Use of thermal energy produced locally (e.g. via CHP) or through thermal storage such as water heating, potentially displacing fossil fuels and maximising use of resources.
Integration of electric vehicles	Potential displacement of fossil fuel powered transport.
Local socio-economic uplift through the renewable energy scheme	There are various business models for this.
Local socio-economic uplift through spin off businesses and similar.	Business creation needs to be shown to be sound and not artificial, and not displacing or disadvantaging similar business nearby.
Real time energy price tracking	With the use of half hourly metering advantage can be taken of lower/higher price periods.
Rural electrification	Cases where development of a microgrid will provide (better) electricity supply. This is most relevant to isolated communities and island systems.
Small scale demand side management	Allows trialling of flexible demand side technology which may attract funding and payments from the service benefactors.
Energy storage	Allows trialling of energy storage technology and techniques which may attract funding and payments from the service benefactors.
Main grid reinforcement avoidance or deferral	Noteworthy that this can be an issue for import as well as export, e.g. Lewis has issues both ways.
Main grid congestion reduction	A benefit to the wider grid by offloading it.
Reduction of transmission and distribution losses in main grid	A benefit of local supply which would otherwise normally be reflected in use of system charges and licensed supplier costs.
Provision of main grid ancillary services	Through the generation or flexible demand or storage technology if used.

Table 6-5: General potential advantages with a microgrid

6.7 When a microgrid might be successful

A microgrid is likely to be successful when it has, as appropriate, considered the points raised in this report, is clear on its costs and value and can present a clear business case. As a minimum a project should have considered the following broad areas.

- Security of supply and power quality – particularly for a true microgrid.
- Main grid constraints and the means to overcome them.
- Supply of electricity at a local level (privately) and the use of a licensed supplier for exchanges of electricity with the main grid.
- Regulatory aspects – most notably licensing, licence exemptions, businesses and business separation, consumer rights of choice, metering and other obligations.
- Technical aspects covering the operation of the microgrid and its component parts but also the interaction and compliance with the main grid.
- Costs covering development, construction, operation and maintenance and end of lifetime.
- Added value such as the use of heat and provision of generated green electricity to replace other fuel sources that may be more expensive or polluting. Also, the potential spin offs in creating new local businesses, other services and funds.
- Health and safety including hazards, risks and liabilities during construction and in operation and at end of lifetime.
- Risks and opportunities that may occur during all phases of the project.
- Other aspects such as financial modelling, consenting, stakeholder engagement, funding, business modelling, development and construction timelines, resourcing and other disciplines.

A microgrid should be enabling new generation, providing local cost efficient and (ideally green) electricity supply to a genuine demand and seeking to add value as far as reasonable and beneficial to do so.

Technically, it will need to be well designed such that the level of control needed is moderate enough to keep the microgrid within sensibly achievable bounds, e.g. if it is trying to soak up too much generation where there isn't really the demand then this is unlikely to prove successful. It should also preferably be well contained and operated over small distances and low voltage to keep costs low.

The project should have access to all the necessary expertise in developing, constructing and operating the microgrid, be well acquainted with the regulatory issues, and well set up as an operational business to cover out common O&M. The microgrid developer should also have considered and be able to deal with risks and issues such as consumers leaving or asking for a third party supply, and take advantage of opportunities such as the lifting of generation constraints allowing further generation opportunity or a relaxation to operational restrictions.

7 Summary

7.1 General

This report has been written by XE to provide high level guidance on the definition and make up of a microgrid, the key issues, advantages and disadvantages and assist in answering questions about costs, value and the likelihood of success. This work is in part a result of an increased level of interest in microgrids within Scotland.

7.2 Definitions

The accepted international definition of a microgrid is a small grid that can run both connected to and islanded (disconnected from) the main (utility) grid. As far as XE is aware, at time of writing, there is only one such operational microgrid in the UK (at the Centre for Alternative Technology – CAT, in Wales). XE has used the term 'true microgrid' in this report to qualify this type of microgrid.

It is also not uncommon for the term 'microgrid' to be used to denote other types of small grids, most notably permanently islanded systems which are never connected to the main grid and 'private wire' systems which are permanently connected to the main grid.

7.3 True microgrids

True microgrids that can run connected to or islanded from the main grid offer the key advantages of improving security of supply and also power quality. This means that when problems occur in the main grid, the microgrid can disconnect and continue to operate. This can be done to maintain supply or to improve power quality, an issue for high value and sensitive consumer loads. Common power quality issues include voltage unbalance, voltage fluctuations, excess range and harmonics.

The main disadvantages of a true microgrid are the costs and complexity which must be set against the value obtained from its defining features.

Given the relatively high level of security of supply attained in Scotland, and the ready availability of cost effective alternatives to a microgrid when the main grid is lost, e.g. back-up diesel and UPS systems, it is difficult to see that much benefit is brought by the microgrid considering its likely overall cost and complexity. Therefore, a true microgrid should have its benefits clearly quantified and its value may be of secondary importance to other aspects which may be obtainable through a simpler business model such as a private wire system - see Section 7.4 below.

It is worth noting that a microgrid in Scotland will almost certainly be a private wire arrangement which in itself offers advantages worth considering, probably over and above a true microgrid.

7.4 Private wire systems

Private wire systems offer a number of advantages but costs and complexity need to be carefully considered. There appears to be one major driver for private wire microgrid systems in Scotland although there are other drivers and benefits.

The main driver is in circumventing main grid constraints on generation export by using electricity locally and privately instead of exporting it to the main grid where strict and low limits on generation export may apply. This then allows connection of (renewable) generation beyond that which would be possible in a traditional directly connected to the main grid renewable generation project.

An additional advantage is that of local electricity supply whereby the renewable generation can be traded locally at prices which can be more attractive than using the GB Market and licensed suppliers. A licensed supplier is however still needed for ‘top up’ from and ‘spill’ into the main grid although their role can be much reduced.

The overall value of the private wire system will depend mainly on its costs set against its benefits. It is far more likely to be cost effective if:

- The private wires are run over a small distance with a relatively high concentration of demand, e.g. a housing estate rather than a dispersed rural community.
- The private wires are run at low voltage rather than using high voltage, e.g. LV implying 230/400V rather than 11kV and 33kV.
- The private wires are required anyway for other purposes rather than duplicating an existing distribution system, e.g. a new housing estate is to be built rather than connecting existing properties already served by a distribution system.
- Technology avoids higher cost items in favour of lower cost options unless there are clear reasons otherwise. For example, current electrical battery storage technology is relatively pricey compared to basic thermal energy storage options such as water and space heating.
- The generation and demand are reasonably matched rather than significant demand needing to be created to soak up excess generation not acceptable to the main grid.

7.5 Island systems

XE has not considered island systems to any great extent within this work. They are not uncommon in Scotland and simply a product of the demand for electricity being too far away from the existing main grid, e.g. Scottish islands such as Fair Isle. As island systems they necessarily exhibit many of the features of a true microgrid in terms of demand and generation flexibility and control and hence many of the issues discussed will still be relevant. Island system developments are however perhaps more to do with basic rights to amenities than adding value in cases of communities already connected to the main grid and hence the value questions are not the same.

7.6 Regulatory issues

The development of microgrids raises a number of regulatory issues. The key issues are in ensuring projects are aware of and can avail themselves of class exemptions from being licensed. This generally means generation should be less than 10MW and distribution and supply activity limited to no more than 1MW of domestic consumers, although the rules are more complex than this and can flex upwards in terms of limits.

Even with exemptions, microgrid projects need to be aware that they do have obligations. One important issue is the rights of consumers within the microgrid to choose their electricity supplier, meaning the microgrid needs to be able to facilitate third party electricity supply across its wires or otherwise show this is not possible or in the best interests of consumers. This has implications for metering systems and the general operational principles of the microgrid as well as the consumers.

7.7 Technical issues

Technical issues will depend on whether a proposed microgrid is a true microgrid that can operate connected to the main grid and disconnected from the main grid (in island mode), or whether it is a stand-alone island system or a permanently connected private wire system.

True microgrids and island systems are the most complex as they require strict operational control in island mode, with true microgrids also requiring interface equipment and control with the main grid to manage the connection and disconnection process. Aside from the basic electrical design issues there are issues to consider around balancing generation and demand and thus flexible load (load that can be controlled and shed) and controllable generation are practically essential. Energy storage such as batteries is also common on such systems as is the use of thermal storage systems such as water and space heating.

Private wire systems that are permanently connected to the main grid are simpler. However, they still require a good level of electrical design expertise and, depending on how they are set up to run operationally, will still require a level of control in operation. These complexities should not be underestimated.

7.8 Costs

Costs have been discussed at some length and due consideration needs to be given to the different phases of a project, broadly development, construction, operation and decommissioning / end of lifetime.

Some broad quantification and guidance on costs has been given above in Sections 4.7 and 7.8.

Costs for true microgrids and island systems will tend to be higher as the level of complexity is higher involving more design, more control equipment, and the costs of control actions such as controlling (constraining) generation, switching consumer demand or using storage technology.

7.9 Other aspects, added value

There are quite a few other aspects to consider in microgrids, some of which are not within the scope of this report, e.g. funding sources, financial models, consenting, etc. As microgrids can be expensive (but not necessarily so) it is important to seek to add value to the microgrid beyond, for example, circumventing a constraint on generation export to the main grid. Examples of this include displacing the use of fossil fuels used for transport and heating and promoting new local businesses or other enterprises.

7.10 Longevity and innovation

A current key driver for interest in microgrids is the inability to apply a standard business model to grid connection of a community renewable energy project. The key issue is constraints on the main grid. Main grid constraints will however in many cases be only a temporary issue being removed through reinforcement within a few years and hence the implementation of a microgrid may only be of value in this context for a short period.

Given the above, added value and an ability to change over time is important. Not many business models have the luxury of being able to remain static and private wire microgrids may find they can connect new or further generation in the future, may find demand increases, or may have to mitigate consumers leaving the system or created businesses failing. Microgrid projects therefore need to be forward looking beyond the time horizons of immediate issues to embrace potential future opportunities and also be able to mitigate potential risks.

Despite this, there is a substantial shift in the electricity sector towards technology and practices that are being seen now at small scale community level such as local supply models, flexible demand, private wires and storage. There is therefore an element of leading edge innovation in many of the schemes, the value of which also needs consideration, e.g. in being able to translate the small scale community initiatives to a wider market.

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