DEPARTMENT OF ELECTRONIC & ELECTRICAL ENGINEERING

University of Strathclyde Engineering

Coupling Demand and Distributed Generation to Accelerate Renewable Connections

Options for the Accelerating Renewable Connections project

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LIST OF ACRONYMS

ANM	Active Network Management
ARC	Accelerating Renewable Connections
CfD	Contract for Differences
DES	Distributed Energy System
DG	Distributed Generation
DNO	Distribution Network Operator
LIFO	Last In First Off
FIT	Feed In Tariff
NFG	Non-Firm Generation (as part of an ANM scheme)
PPA	Power Purchase Agreement
PW	Private Wire
VPW	Virtual Private Wire
ROC	Renewable Obligation Certificate

1 EXECUTIVE SUMMARY

The objective of this report is to layout the options for coupling demand to distributed generation (DG) under the Accelerating Renewable Connection (ARC) project. The report covers renewable distributed generators with connection agreements lower than the installed generation capacity (export limited firm connections) as well as distributed generators connected with non-firm connection agreements, both managed under an Active Network Management (ANM) scheme. The objective is to highlight ways in which demand can participated in providing flexibility for the benefit of DG that would otherwise be curtailed.

The report lays out a range of architectures for operating Distributed Energy Systems (DESs) which contain local demand and DG. The concept of a DES is that demand is supplied by local DG either using privately owned distribution assets or a public distribution network owned by a Distribution Network Operator (DNO). Operation of a DES can help manage variability in DG output, reduce curtailment in ANM schemes and assist the DNO in managing network constraints. They also provide a move towards local trading of electricity with potential financial and non-financial benefits to both distributed generators and local demand customers.

The combined effect of a DES on the distribution network can be characterised by the *net power injection* – that is the generated power minus the demand. The *net power* represents a DES's contribution to any network constraints, and as such there is the potential for schemes to receive connection capacities based on net power rather than generated power.

The architectures discussed range from a simple behind-the-meter options to a complex local market scheme. It is expected that ARC will provide the opportunity to deploy some of these architecture on the ground, and to model others as part of a wider program of learning.

This report identifies several areas in which setting up a DES may create challenges.

- **Operational challenges:** Combining demand and DG requires that the scheme is capable of controlling the net output as opposed to the generated output. This creates additional complexity as additional measurements and control logic are needed. Operational requirements include the need for secure failsafe systems to ensure that the network remains safe and secure during fault conditions. When operating within an ANM scheme, the DES must meet ANM requirements such as response time-scales.
- **Electrical connection arrangements:** The electrical link between demand and DG can take several forms depending on their geographical location and the relative number of sites involved. Demand and DG within a DES can be electrically linked across the DNO owned distribution network or via privately owned infrastructure with a single point of connection to the distribution network. In both cases the contribution to any network constraints must be considered, including the roll of electrical losses.
- **Communication challenge:** Communications within a DES and with other systems such as an ANM system are required for secure operation. ANM schemes have the potential to interface with demand as well as distributed generators, although with a larger number of demands (for example if using domestic demand at multiple houses) it is likely that an aggregator will be required to provide a single point of contact between the DNO or an ANM scheme and the flexible demand.
- **Commercial arrangement:** The commercial arrangements needed to run a DES are themselves novel. The model chosen depends on whether flexible demand is located on the

same site as the generator, and on whether the scheme is connected using a private network or the public distribution network. In all cases, the arrangements must satisfy the regulatory requirements. Note that under current policies, commercial arrangements between generators, demand and supply companies do not directly involve the DNO, however it is important that the DNO is aware of how such schemes may wish to organise and operate so as to provide guidance on the feasibility of the connection options for such schemes.

- **Regulatory issues:** DG, distribution and supply of electricity are all licensed activities and meeting the full licence conditions is likely to be well beyond the means of a community project. A number of options exist for smaller schemes to reduce the financial and risk related burdens that licence conditions place on participants. These include licence exemptions and a new 'licence lite' option discussed in Section 6 of this report. Alternative methods of meeting regulatory requirements are possible, for example linking the schemes to larger supply companies which can provide services as licensed providers.
- **Principles of access:** A clear principles of access is needed under any scheme to ensure clear simple and fair distribution of curtailment among multiple generators, and the inclusion of DESs and the roll of demand in managing curtailment must also be considered. Existing ANM principles of access based on Last in First Off (LIFO) are clear and simple and allow for relatively easy estimation of likely curtailment. However, these estimates often make use of the expected demand levels on the distribution network when determining the 'network capacity'. The move towards flexible demand has the potential to disrupt these assumptions and calculations. Schemes developed in conjunction with one particular generator can therefore affect curtailment applied to other generators. Therefore the bounds within which DESs will operate should be clearly defined at the roll out of ANM to provide certainty to all participants.

The report explores each of these issues before suggesting four potential DES architectures for further investigation. These have been chosen to highlight aspects that are most likely to be of interest to the ARC project. Aspects of each can be combined or disregarded depending on the specifics of any project included within ARC. The four investigated architectures are:

- **Physical private wire systems:** The connection of DG and demand over private owned distribution assets and a single point of connection between the scheme and the DNO owned network.
- **Virtual private wire system:** A link between generators and either one, or a small number of flexible demands within the DNO owned network. Such a scheme is suitable for operation behind a point of constraint on the network.
- **Demand aggregators:** Flexibility is achieved by responses from a large number of small demands, such as domestic properties. This flexibility is aggregated to provide a significant overall affect. The aggregator itself acts as a point of contact for the ANM scheme and associated generators and also manages participation of flexible demand so to achieve requested flexibility at times when needed.
- **Local markets:** Demand and DG engage in a local market to either increase demand or decrease generation in such a way as to avoid constraints.

Finally, potential DES projects in the ARC areas are identified.

2 INTRODUCTION

This report is produced as part of the Accelerating Renewable Connections (ARC) project for Scottish Power Energy Networks. It is an investigation of the options for using local demand to accelerate the connection of renewable DG capacity, with specific reference to community renewables within the ARC region.

The distribution network in several areas of the Scottish Borders and East Lothian is close to capacity in terms of DG connections. Allowing further DG connections in these areas will involve some limitations on the new generator outputs. One method being deployed in the ARC project is the use of Active Network Management (ANM) which connects new generators under non-firm connection agreements. This allows the ANM scheme to curtail non-firm generation if required to maintain network limits, and is in contrast to firm connections where generators are guaranteed network access up to the defined capacity.

Another option in ARC project is the use of export limited firm connections in instances where the connection capacity is lower than the maximum output of the generator. This solution places a fixed limit on what may be exported into the network with a possibility of additional generation if it is consumed locally.

In the case of variable renewable generators such as wind, solar and run-of-river-hydro, both non-firm and export limited connections will lead to the loss of opportunity to generate electricity from free, clean renewable sources. Thus, local flexible demand presents an opportunity to use this otherwise curtailed generation.

The concept of reducing curtailment through the action of local demand is intuitively simple, but the practicality of implementing such a scheme can be complex. Firstly, any scheme needs to maintain the technical integrity of the electrical system including fail safe mechanisms that satisfy the Distribution Network Operator (DNO) operational requirements. The commercial arrangements between generator and demand must satisfy electricity regulation and maintain the liberalised market principles of competition in the wholesale and supply markets. Generation, supply and distribution activities are usually licensed activities and any scheme undertaking any of these must either fulfil licences requirements or qualify for exemptions. Finally, if operating as part of an ANM scheme, a local energy project must be capable of integrating with the communications, control systems and wider principles of access imposed by ANM.

3 THE BENEFITS OF COUPLING ELECTRICITY DEMAND AND DISTRIBUTED GENERATION

Within ARC there is the potential for both demand customers and generators to benefit from coupling together to form a Distributed Energy Scheme (DES). Such schemes have been rolled out elsewhere in the UK[1]. Benefits can take the form of financial incentives with increased payments to generators and decreased cost of energy for consumers. There are also significant reputational benefits, for example through the traceability of electricity that such a scheme can provide. DES schemes can reduce congestion further up the distribution network and there may be a benefit to the DES in terms of reduction of Use of System Charges for demand and generation, and to the DNO in terms of infrastructure investment deferral.

The exact nature of the benefits available to demand customers and generators will depend on the type of connection agreement available to the generator. Until recently only firm connections agreements have been available, and therefore most distributed generators operate under a full, firm connection agreements giving them network access at all times up to their rated capacity; such an arrangement is considered business as usual. Most DNOs will consider providing an export limited firm connection, lower than the generator's rated capacity if the ability of the generator to maintain the connection offer limit is confirmed. More recently, the development of ANM has led to some DNOs offering non-firm connections agreements in areas in which ANM is being rolled out.

Types of DG connections

The following three types of connection are considered in this report:

- **Full firm connection:** This has, to date, been the standard connection offer in which the generator receives a firm connection equal to the rated capacity of the generator. Where network congestion is not an issue the cost of this connection will include the works relating to connecting the generator to the local distribution network; the time scale depends on the level of work required and in most cases will be of the order of months rather than years. If the connection of the generator has the potential to breach network limits further up the distribution network, the connection cost will include the costs of reinforcing the distribution network to maintain these limits. In most cases, the cost and time-scale associated with distribution network upgrades will be beyond community or small renewable schemes. Such schemes which require significant network upgrades will not be financially viable.

- **Export limited firm connection:** If there is limited capacity for DG to connect to the local distribution network, a generator can be offered a firm connection for part of the proposed DG capacity. Accepting such an export limited connection will result in the generator being de-rated to the capacity of the connection offer. This reduces potential income, however investors may accept such an offer if the economics of the scheme remain viable, or if there is the potential for greater network capacity to be released in the future. An export limited connection can allow a generator to get some network capacity without the cost and time associated with extensive upgrades to the distribution network.

[1] For example:
Findhorn Eco-Village: http://www.ecovillagefindhorn.com/findhornecovillage/renewable.php
Ashton-Hayes: http://www.goingcarbonneutral.co.uk/microgrid-study-informaton/

- **Active Network Management non-firm connection:** A non-firm ANM connection offer provides no firm connection level, but provides network capacity to a generator up to its installed capacity according to a defined principle-of-access (see Section 5.2 for definition and further discussion). At any time, the maximum generator output can be limited to any point between the zero and maximum capacity, and the generator must respond to ANM curtailment signals by reducing generation to below the specified level. In existing ANM schemes, non-firm connection offers include a non-binding estimate of likely curtailment levels. These estimates are typically calculated using historical data. If only minor curtailment is predicted, the generator will expect to generate at full capacity the majority of the time and the project is likely to be financially viable. As with export limited connections, an ANM offer removes the cost and time associated with network upgrades in return for reduced network access and passes the curtailment risk to the distributed generator.

For each of the network connection types there are benefits associated with coupling demand to generators in a DES. In each case generators and demand customers will compare the benefits associated with participating in a DES with those associated with standard arrangements; only where the benefits of a DES are greater will a scheme be viable. For generators with full firm connection agreements, a DES will need to provide benefits which the generator feels are more valuable than those which can be realised under a standard power purchase agreement. For example, if a generator can get a power purchase agreement that pays £50/MWh the DES arrangement must either provide a higher price per MWh, or other benefits such as reduced risk or reputational benefits associated with supplying local demand.

For generators experiencing curtailment, either under Export Limited Firm Connection or ANM, curtailed generation represents a loss of revenue. Therefore, the ability of a DES to reduce curtailment allows the generator to derive some benefit by potentially reducing the curtailment for a significant period of operation.

Table 1 gives a summary of the benefits associated with demand and DG in a DES, as well as the specific benefits relating to generators. Each type of connection agreement is discussed below.

Benefits of a DES associated with full firm connected DG

With a full firm network connection, the generator does not have the risk of curtailment. All of its generation can be sold under standard agreements with a supplier, usually through a Power Purchase Agreement (PPA). For small generators, the price per unit in the PPA will usually be set by the relevant Feed In Tariff (FIT) rate, while for larger generators income will also be generated by the sale of Renewable Obligation Certificate (ROCs).

In this situation, although a generator with firm connection does not face curtailment, it can still benefit from taking part in a DES if it can negotiate a higher price for its power output. For example, a number of reports suggest that it has been possible for large renewable schemes to sign a sleeving agreement which involves a demand customer, the generator and a supply company[2]. These reports also indicated that the size of project that can be supported by such an agreement is up to 30MW[3]. For generation covered by FIT arrangements, current relatively high tariff levels in the UK mean that it will be very difficult to negotiate a price higher than their FIT rate. For example, wind installations of less than 1.5MW will receive 9.79 p/kWh or more under the current FIT arrangements plus a 6.64

[2] http://www.burges-salmon.com/Sectors/energy_and_utilities/Publications/Direct_PPA_update_November_2011.pdf

[3] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224081/baringa_ppa_market_liquidity_call_for_evidence.pdf

p/kW export bonus. Standard domestic electricity tariffs are in the region of 15 p/kWh. Only generators greater than 1.5MW have any possibility of negotiating upwards of their FITS tariff rate[4].

The benefits for demand customers participating in a DES include non-monetary benefits related to the local, renewable and traceable nature of the electricity used. Domestic and business customers may consider buying electricity guaranteed to be from locally owned generation even if the prices are similar or slightly higher than those on the open market as it can provide a guarantee that their payment goes directly to a local renewable generator.

The creation of DES schemes involving generators with full, firm connection agreements is unlikely to form part of the ARC project, however it should be noted that the benefits discussed will roll over to schemes involving generators with export limited and non-firm connections.

Benefits of a DES associated with an export limited firm connected DG

With an export limited firm connection agreement, the technical ability of a generator to produce electricity beyond the connection limit is of zero value. To access any benefit from the capped generator capacity, a DG needs to find a way of using that additional generation to supply local demand that is behind the network constraint that is casing the limited connection.

For wind, solar, and run-of-river hydro generators, the short-run cost of generation is close to zero. Therefore the ability to receive even a small revenue from generation beyond its export limited capacity represents a net benefit. By comparison, demand customers under normal arrangements pay the market rate for supply of electricity; during 2013 this was approximately 14 p/kWh[5]. Therefore a DES which allows export-limited generators to be paid even a low price for generation beyond the export limit and allows customers to pay less than 14 p/kWh can provide greater benefit to both generator and demand customers when compared to standard arrangements.

Whilst there is obvious benefit in the use of a DES to increase generation beyond the export-limit, all generation up to the export limit can be sold under a standard PPA and as in the case of a full-firm connection agreement. The quantity and timing of ‘additional generation’ that would otherwise be curtailed’ depends on the generator type and will have an impact on the frequency with which these benefits can be realised. For a run-of-river hydro scheme with a good resource, there is the potential to generate at full capacity for a significant proportion of the year. For a wind generator, the availability of excess generation will depend on the available wind resource. Therefore the design of a DES scheme will need to take into account the likely availability of otherwise curtailed generation. As an example there is a question over whether demand customers buy all their electricity through the DES or retain existing supply arrangements for the majority of their supply with the DES acting as a ‘top up’. These decisions depend in part on the likely distribution across the year of generation that would otherwise be curtailed.

Any arrangement to set up a DES to administer the use of otherwise curtailed generation will need to be discussed with the DNO providing the connection. The DNO has a responsibility to ensure that any network constraints are safely managed.

Benefits of DES associated with Active Network Management managed DG

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[4] http://www.fitariffs.co.uk/FITs/principles/export/

[5] https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics

The benefits for non-firm generators in an ANM scheme of making use of otherwise curtailed generation are similar to those associated with export limited firm connections. Under existing ANM arrangements, curtailment instruction must be observed by the reduction of generation. Curtailed generation therefore has zero value. As with export limited connections, both DG and demand will benefit if a DES can arrange for that otherwise curtailed generation to be used, and if they can agree a price which is less than a f market rate for supply of electricity (which in 2013 was less than 14 p/kWh).

With an ANM connection, the timing of curtailment is less certain and more likely to show significant seasonal variations when compared to that of an export limited connection. For example if base-load demand is significantly higher in winter than summer, curtailment under ANM may occur almost solely during summer.

Table 1: A summary of the benefits accruing the generators and demand consumers under a DES.

Connection type	**DES advantage to Generator**	**DES advantage to Demand**
Full firm connection	- Potentially increased price per unit of generation compared to available PPAs	- Reputational benefit from traceable, local and renewable electricity
Export limited firm connection	- Ability to increase generation beyond export limit - Potentially increased price per unit of generation compared to available PPAs	- Reduced costs of electricity - Reputational benefit from traceable, local and renewable electricity
Active Network Management non-firm connection	- Ability to generate beyond the current ANM calculated limit - Potentially increased price per unit of generation compared to available PPAs	- Reduced costs of electricity during curtailment events - Reputational benefit from traceable, local and renewable electricity

In the discussion above it is assumed that the short run cost of generation is close to zero and once curtailed the ability to generate from that resource is lost. This is true for many renewable technologies such as wind where there are no fuel costs and the wind resource cannot be stored. For non-variable renewable generators such as Anaerobic Digesters these assumptions are not necessarily true. Anaerobic Digesters burn fuel which can be stored and reducing generation for a curtailment event means the fuel can be stored and used later. The economics for these cases therefore depend on the relative availability of fuel compared to the capacity of the generator. If there is an excess of fuel, curtailment means losing the opportunity to use fuel; whereas if there is a scarcity of fuel curtailment does not mean the loss of opportunity to generate, as fuel could be stored and used later.

Synthesising these benefits into a workable commercial model is a significant challenge for any DES scheme and will involve negotiations involving generators, demand customers and suppliers. The DNO is not involved in setting these arrangements, however distribution networks are important in facilitating DESs, and DNOs must ensure that any scheme maintains the integrity and safety of its network. It is important for DNOs to understand some potential mechanisms for realising these benefits so that they begin to understand the likely requirements for such schemes and the actors with whom they will need to engage.

4 SOURCING DEMAND FOR DISTRIBUTED ENERGY SCHEMES

Sourcing and using demand efficiently within ARC is a key challenge of the project. To allow the benefits associated with reduced curtailment, demand must be electrically located behind the constraint causing curtailment. There are a wide variety of models that use demand to support renewable generators, and the most suitable model depends on the characteristics and locations of the demand customers and generators.

This section discusses some of the important categories of demand that are relevant to ARC. Five classifications are defined and are discussed below:

Uncontrolled	or	Flexible Demand
New	or	Existing electrical demand
Generator-specific demand	or	Non-generator specific demand
Behind the meter demand	or	Demand connected via the distribution network
Small number of large demand customers	or	Large number of small demand customers

Uncontrolled or flexible demand

The vast majority of electrical demand is uncontrolled. Most domestic and business consumers can draw any quantity of electricity at any time up to some maximum power. Under some tariff arrangements, such as *economy 7*, there is an incentive to use electricity at certain times of the day through low prices at off-peak times. In few areas, particularly those with high penetrations of electrical storage heating, some demand is controlled by radio teleswitching which spreads the charging of heaters across the night.

Demand customers connected in a DES can provide benefit to generators whether operating as flexible or uncontrolled load. For uncontrolled demand, curtailment is reduced by the co-incidence of demand with generation curtailment. If demand customers have the ability to provide flexibility, curtailment can be further reduced by manipulating the demand profile so that demand is increased when generation would otherwise be curtailed.

Flexible demand has the potential to provide greater benefit than uncontrollable demand in terms of reducing curtailment, but at the expense of greater complexity. The provision of flexibility by demand is a service and demand will expect payment in return for those services. This payment represents a share in the benefit created by increasing generation by the associated DGs or for the postponement of infrastructure reinforcements by DNOs.

New or Existing Electrical Demand

New electrical demand can consist of either completely new demand for energy (e.g. new housing developments) or the conversion to electricity of existing energy demand currently served from other energy sources, such as heating oil. New electrical demand adds to existing electrical demand and at no point does it reduce the existing demand profile. For this reason, a DES using new electrical demand can be integrated into a distribution network and an ANM scheme without adversely affecting other generators. The minimum demand outside the DES remains the same, and the network capacity available for other generators is not reduced.

Allowing existing electrical demand to form part of a DES can, by contrast, affect other generators. Existing uncontrolled demand moved into a DES means that both the remaining minimum power demand and total remaining energy demand outside the DES are reduced. This is particularly important within an ANM scheme when converting uncontrolled demand to flexible demand. Flexibility in existing electrical demand does not create more network capacity for generators to access the network, instead it re-distributes network capacity to the benefit of one or more generators, and potentially to the determent of others; generators that suffer may feel unfairly treated (For an illustrative example see Section 5.3.1.)

Ensuring that all users of the distribution network are fairly treated must be a consideration when designing a system that incorporates DESs. This does not exclude the use of flexibility provided by existing demand. For example, an option is to make clear at the start of a project that generators accept the risk that network demand can fluctuate. Secondly, demand flexibility can be managed under a well-defined principle-of-access as part of a wider ANM scheme. It is important to consider the consequences of allowing existing flexible demand to integrate into a DES as there is the potential in the future for demand customers to use their right to change supplier to opt into schemes beyond the control of the DNO.

It is important that any scheme facilitated is fair. However it should be noted that it may not be possible to prevent existing electrical demand from choosing to take part in a scheme which provides time-varying tariffs. If such a scheme can be operated within regulatory constraints, the principle of competitive supply requires that customers can change to any supplier operating in such a way.

Generator specific demand or non-generator specific demand

Where a generator project is only marginally viable due to significant expectation of curtailment, the ARC project aims to allow that generator to investigate and develop arrangements with local demand to reduce curtailment. Such entrepreneurial generators will need to be assured that any benefits created by these arrangements accrue to them.

As part of a behind-the-meter system, the export from a DES will be constrained and demand connected behind the meter can agree to be managed by the DES within the export constraint. As such in this situation the scheme can be managed for the benefit of the specific generator. If the demand has a separate connection this is not necessarily the case.

Within an ANM scheme, generators which receive more curtailment are more likely to develop DESs than those that are only curtailed occasionally. Under existing ANM principles-of-access demand behind a constraint is part of the network capacity shared out according to a principles-of-access. The principle-of-access in existing ANM schemes do not provide the option of associating the network capacity created by particular demand to particular generators and therefore overriding the existing principles-of-access. To ensure that a particularly generate receives the curtailment reduction due to demand in a DES, but not connected behind the meter of that generator, an ANM scheme must monitor both generation and demand and associate the two as part of a modified principle-of-access.

As an alternative to generator-specific demand, two alternative models can be used in which demand is not linked to a particular generator. The demand customer may act autonomously and offer flexibility to any generator or to a DNO or ANM operator directly. For example, demand flexibility can form an aspect of the network managed by the ANM scheme, a method being trailed in the Shetland Islands[6]. Under this model, the ANM operator will treat demand flexibility as a control action and

[6] http://www.ninessmartgrid.co.uk/

defines a ‘principle-of-access to flexibility’ which clearly lays out how demand flexibility will be dispatched. The principle-of-access to flexibility will provide the same level of clarity, transparency and fairness in the dispatch of flexible demand by the ANM as is currently achieved through existing principles-of-access to network capacity.

Behind the meter or distribution network connected demand

There are two options for the electrical connection of DG and demand: either through privately owned electrical infrastructure or across the DNO network. In the case of privately owned infrastructure, the demand can be either on the same site as a generator (on-site demand), or a privately owned distribution network can link the two (Physical Private Wire). Both schemes are examples of ‘behind the meter’ demand where the DES has a single point of connection to the DNO which can act as a single metering point. The connection agreement with the DNO will be for this single point of connection and will including import and export capacities. It is the net power export form the DES (rather than the generated power) which will be limited by an export limited or non-firm ANM connection. An example of a connection for a DES would be a fixed import connection capacity agreement and an ANM managed, non-firm connection agreements for export.

A DES in which demand and DG have separate connections to the DNO network involves power flows between them across the distribution network (A Virtual Private Wire). DNO involvement is greater in such a scheme and there will be a requirement to pay use of system charges to the DNO for the power flows between generator and demand. More complex metering arrangements are required with real-time measurements at multiple sites needing to be combined. For either an export limited connection or a non-firm managed connection, the DNO must allow the connection capacity limit to be applied to the net power injections of demand and generation (taking consideration of loses if required) rather than the generator output. The generator may be exporting onto the network above the current network capacity available to the DES, but the combined contribution of the demand and the generator will still need to abide by any constraint imposed by the DNO.

Small number of large demand customers or large number of small demand customers

The demand aspect of a DES can be provided by either large demand customers such as industrial units or small demand customers such as domestic premises. The size of demand, or demand flexibility that is significant in terms of generator curtailment depends on the relative size of the generators and the expected curtailment levels. Single large demand customers may provide significant flexibility whilst allowing relatively simple monitoring and control within the DES. However, providing significant demand and demand flexibility from domestic demand will require the aggregation of many houses. The additional complexity needed to incorporate large numbers of small demand customers may best be managed through the use of an aggregator carrying out monitoring of individual demands, aggregation of response and disaggregation of required control actions. Using a single entity such as an aggregator to manage many small demand units also allows the large DES system to make use of statistical smoothing effects to simply the overall demand response to the DES scheme.

4.1 ILLUSTRATING FLEXIBLE DEMAND OPTIONS

Many of the issues involved in coupling demand and DG in DESs are best discussed in terms of concrete examples. Three possible scenarios for flexible demand that are most relevant to projects that may form part of ARC are briefly discussed below.

4.1.1 Example 1: Small industrial process customer several miles from a wind farm in ANM

Small and medium sized manufacturing companies often have a demand for energy. Examples relevant to rural Scotland include Distilleries, Breweries, and small factories. This example considers such a small factory with demand in the range 50kW – 200kW. The factory owners are considering investing in a wind turbine development 2 miles away which will be part of an ANM scheme. Initially, curtailment analysis suggests that the wind farm project is only marginally viable due to relatively large expected curtailment.

Option 1: The owners of the factory decide to build the wind turbine and link it to the factory by private wire. They apply for the existing 200kW import connection to be extended to allow export. This is granted but is given an ANM connection requiring the export be subject to curtailment.

The export part of the connection will form part of the principles of access of the ANM scheme. Net export from the site will be monitored by ANM and curtailment instructions based on this value rather than the generation. The net export will be curtailed less often than the raw generation; and in the event of curtailment there may be the opportunity for the factory to increase demand instead of reducing generation.

The additional of the wind turbine will also reduce the net demand seen by the distribution network. At present, all the factory's demand contributes to the network capacity available to all non-firm generators in the ANM zone. By building and connecting the generator in this way other non-firm generators may see greater curtailment levels. However there is no grounds on which such change of net demand can be prevented.

Option 2: The owners of the factory decide that it is infeasible to build, maintain and operate the private distribution line and approach the DNO to arrange a Virtual Private Wire (VPW) system with a separate connection to the distribution network, but with the net export of the virtual system being given an ANM managed non-firm connection. The wind turbine and the factory are connected to the same radial feeder, behind the same constraint being managed by ANM. The internal control system required to manage generation and demand to ensure control of maximum export is similar to that in option 1, but electricity flows between the generator and demand across the DNO network.

If allowed, the overall effect of the Option 2 is the same as Option 1 without the need to build the additional privately owned distribution circuit. Other non-firm generators will experience the same reduction in curtailment as in Option 1. In this case there is the potential that these generators will see the Virtual Private Wire as unfair as the DNO has changed its operating principles to the benefit of one generator at the expense of others.

Option 3: A community group proposes to build the wind farm in conjunction with the factory owners who intend to expand the factory, doubling its demand.

In this case, the *additional* demand associated with the expanded factory can be considered as being created in this location *because* of the community wind development: the factory is only expanding because of the availability of local renewable generation. The new wind farm has a strong claim that it should receive all the benefits associated with the new demand even if connected under a VPW scheme. Despite this, there is still the potential that other generators will see such an arrangement as unfair if there an assumption of natural demand growth formed part of the initial curtailment estimates for the lifetimes of the non-firm wind farms.

4.1.2 Example 2: Dairy farming with Anaerobic Digestion with a limited capacity connection

A farmer has applied for a connection for a 100kW anaerobic digester. DNO studies suggest that there is only 50kW of firm network capacity available and offer an export limited 50kW firm connection. The farmer accepts this offer and converts his milking parlour to electricity leading to new electrical demand in the range of 0 – 25kW.

The new demand is 'on-site' and the farm will keeps a single import/export link. The farmer benefits directly from the electricity generated as this reduces import and therefore electricity bills. The farmer will also receive FITS payments for generation and any export from the scheme, however even with the additional demand the generator will continue to operate below full capacity.

The next-door farm is interested in installing a similar scheme and converts to an electric supply for its milking parlour and offers to buy electricity from the first farmer.

The second farm can be connected to the first either through a physical private wire (Example 1, option 1) or a virtual private wire (Example 1, option 2). In the case of a physical private wire, the two farms can come to a private agreement as to the supply of electricity as long as the system continues to satisfy the DNO in terms of limited export. In the case of a VPW, the new electrical demand at the second farm is developed specifically because of the available local renewable generation. In this case, a DNO may be happy to facilitate a VPW system as long as they were satisfied that the 'virtual' export of the system was limited in a similarly robust manner as export from a single point-of-connection.

4.1.3 Example 3: Eco town offering aggregated demand flexibility to participants in an ANM scheme

Approximately 500 households in an aspiring eco town come together to provide demand flexibility through an aggregator. The objectives of the scheme are to reduce their electricity bills whilst making as much use of local renewable generation as possible.

Option 1: The eco town organisers approach one or more individual generators suffering curtailment with the objective of creating sleeving agreements (see section 6) for the fulfilment of demand. These sleeving agreements allow output from these generators to be netted off against the associated demand in real time using smart meters. When there is an excess of demand the aggregator buys additional energy from a supply company, when there is an excess of generation the generator sells to the market through a standard PPA with a supplier.

Such a scheme is a more complex example of a simple Virtual Private Wire based DES as described in examples 1 and 2, above. The net of total generation minus total demand may be considered as the injection to the distribution network. The DNO has no part in the financial arrangements between demand customers, the aggregator acting as a supplier, and the generators. However, it is the DNOs decision on whether to allow increased output from the associated generators based on the action of the aggregated demand.

Option 2: The eco-town offers the flexibility to increase demand to the current marginal generator during any curtailment event. Generators can choose to 'buy' the flexibility by splitting the increased revenue with the demand aggregator through a rebate payment.

Under Last In First Off (LIFO – see Section 5), a common principle-of-access, an increase in demand will lead to a reduction in curtailment at the 'marginal generator'. All other non-firm generators will be at either full output or full curtailment. An offer to increase demand (in return for payment) can be made by the aggregator to the current 'marginally curtailed' generator.

Alternatively, if allowed within a modified principle-of-access, an agreement can be reached between an aggregator and any currently curtailed generator outside the standard principles-of-access. Under this arrangement, LIFO can be used to define the initial curtailment whilst excluding demand flexibly, then trading takes place with respect to that initial curtailment.

Option 3: Offer a service to the ANM scheme which allows the ANM operator to schedule demand flexibility

The ANM scheme agrees to provide control signals to the aggregator in a way that leads to the optimal overall system solution rather than attempting to maximise the benefit to a particular generator. The ANM scheme creates the schedules and directs the aggregator as well as curtailing generators. It then informs generators of the reduction in curtailment they received due to the demand flexibility. All generators in the ANM scheme must agree to these arrangements, and to the mechanism for defining the 'cost' of curtailment reduction before connecting. It is also important that the calculation by the ANM scheme of curtailment reductions is transparent so as to ensure participants feel fairly treated.

5 FLEXIBLE DEMAND AND ACTIVE NETWORK MANAGEMENT

The integration of flexible demand or DESs within an ANM system creates new technical and commercial challenges. The design of existing ANM schemes focuses on the curtailment of generation to manage thermal and voltage limits. Constraint locations are monitored in real-time, and as they approach limits, trim and trip actions can be taken to reduce the output of non-firm generators behind that constraint. The design of control actions is based on detailed electrical modelling of the systems including demand levels, generation and demand ramping rates, power flow limits etc. In real time however, the curtailment is controlled simply in response to predefined power flow limits.

Incorporating the action of demand within an ANM scheme requires changes to ANM schemes and to the interpretation of measurements and set points. This section reviews current ANM concepts and discuss the potential for including flexible demand in future schemes.

5.1 EXISTING ACTIVE NETWORK MANAGEMENT

The active management of distribution networks has developed in the UK over the past decade driven by high demand for the connection of greater capacities of renewable DG. ANM – as pioneered on Orkney[7] – extends traditional limits on DG capacity to make greater use the excellent wind resource. Upgrade of the Orkney distribution network is expensive due to the high cost of undersea cables to links the islands with the UK mainland; upgrading is estimated to cost in the order of £30M.

The Orkney ANM scheme has allowed the capacity of distributed wind generation to increase from 26MW before the scheme to 65.4MW in 2013. Of the new wind generation, 21MW is controlled via an intertrip which trips the generators only in the event of a fault on the undersea cables. The remaining 18.5MW is managed in real time with generators being instructed to trim output to maintain thermal limits across the distribution network[8].

ANM has also been rolled out on the Shetland Islands as a method of managing the stability of the Islanded distribution network as well as potential future thermal and voltage issues. On the UK mainland ANM is proposed in a number of Low Carbon Network Fund (LCNF) projects notably: Low Carbon London, Flexible Plug and Play, and ANM is mentioned in the business plans of all DNOs for the RIIO-ED1 price control period.

5.2 ACTIVE NETWORK MANAGEMENT CONCEPTS

This section defines the ANM terminology used in this report:

Firm Generation: Distributed generation with the firm right of access to the network at all times. The total firm capacity should be no more than the total generation that can be injected into the distribution network under conditions of minimum demand.

Non-firm generation: Distributed generation capacity that is not guaranteed access to the network at all times. When network capacity is limited, non-firm generation will be curtailed so that total generation does not exceed the current network capacity. There is no requirement to reimburse non-firm generation for lack of network capacity.

[7] http://www.ssepd.co.uk/OrkneySmartGrid/

[8] The terminology relating to the Orkney scheme differs from that used in this report. The Orkney specific terminology of Non-Firm Generation and New-Non Firm generation are not used in this report.

Network Constraint: A limit on the capacity of the local network to absorb power from distributed generation without exceeding network limits. In most distribution networks, limits are either thermal or voltage limits. The fundamental limit on a thermally constrained zone is the current carrying capacity of the power lines and transformers to export electricity. A voltage constraint limits DG capacity due to the voltage rise effect: the voltage on a distribution feeder tends to rise when there is an injection of power onto the feeder as power must flow back up the feeder and too much generation can push the voltage outside permissible limits. The voltage rise affect depends on the up-stream voltage, the action of voltage regulating devices, local demand and reactive power injections and demand.

ANM zone: The distribution network can be divided into zones based on the location of network constraints. A zone consists of all the network 'downstream' of a particular constraint. Generators within a zone share the zone's network capacity according to a Principle of Access (see below). Constraints can occur at different depths within a distribution network leading to nested zones. Power injected by a non-firm generator within a nested zone contributes to more than one constraint, and its output must be considered when managing all the constraints to which it contributes.

Network capacity: The network capacity is the total generation that a network or zone can absorb without breaching its network constraint. Network capacity varies in time depending on the current demand. In the case of a thermally constrained zone, the network capacity is the total export capacity from the zone and the current demand. For example a limit of 10MW export and a local demand of 5MW give a network capacity of 15MW. The concept of network capacity is used in studies to estimate curtailment and network operation however there is no measurement of network capacity. Instead it can be inferred using a measurement of power flow through a constraint, total generation within the zone and a network model. (See Section 5.3 for an example).

Principles of Access: When multiple non-firm generators connect within a particular ANM zone, limited network capacity must be distributed between the generators. A clear, fair and efficient Principle of Access to the network capacity is needed to provide a method of distributing network capacity between non-firm generators. The most common is LIFO, a form of priority order in which the highest priority generator (in this case the first to connect) always has first access to the network capacity, the second priority generator gets second priority access etc.

5.3 An Illustration of Active Network Management

The concepts defined above are best illustrated through a simple example. Figure 1 shows an example network and illustrates network constraints and zones. It shows that Zones 1 and 2 are nested within the core zone.

Zone 1 has two associated non-firm generators (NF1 and NF2), and the output of these and the firm generation (firm1) have the potential to breach the thermal limit exporting from Zone 1. The Network Capacity available to generators in Zone 1 is given by:

$$P^{NC}_{zone1}(t) = P^{export}_{zone\ 1} + P^{demand}_{zone\ 1}(t)$$

where $P^{NC}_{zone1}(t)$ is the total network capacity available in zone 1, $P^{export}_{zone\ 1}$ is the maximum export capacity of the distribution network and $P^{demand}_{zone\ 1}(t)$ is the current demand in zone 1. $P^{NC}_{zone1}(t)$ defines the maximum generation that can be accommodated in zone 1 at this time so:

$$P^{NC}_{zone1}(t) > P^{gen}_{firm}(t) + P^{gen}_{NF1}(t) + P^{gen}_{NF2}(t)$$

Network capacity in zone 1 varies with time due to the changes in demand1; it will always be greater than the capacity of generator firm1 but if demand is low and generation at all 3 generators are high, network capacity may be less than the combined output of firm1, NF1 and NF2. Limited network capacity for zone 1 is shared between NF1 and NF2 according to a LIFO principle of access in which NF1 has greater priority than NF2. It should be noted that in a deployed ANM scheme 'network capacity' is not known as demand is not metered in real time. Instead network capacity is inferred from the monitoring of the thermal constraint. Increasing Demand1 will increase network capacity (and therefore reduce curtailment) but the only measurement will be that of power flow out of zone 1.

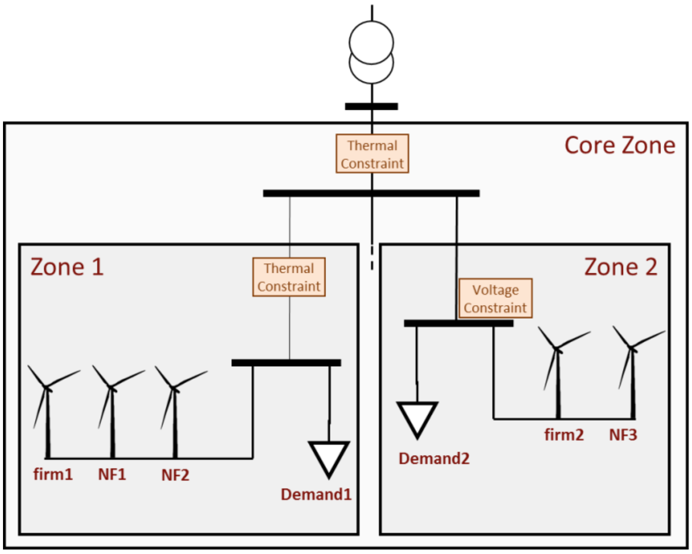

Figure 1: Example ANM scheme showing constraints and zones. Zones 1 and 2 are nested within the Core Zone.

Zone 2 has one associated non-firm generator and its output is limited by a voltage constraint. When demand2 is low and generation from NF3 is high, the voltage of the bus within zone 2 can breach the upper statutory limit on distribution voltage levels. The calculation of network capacity for zone 2 is more complex than that for zone 1 as it depends on real and reactive power injections and demands and voltage management devices such as tap-changers and voltage regulators.

Both Zones 1 and 2 are nested within the core zone and network capacity related to this zone is constrained by a thermal limit on export via the Grid Supply Point. Core zone network capacity is defined in the same way as zone 1. The principle of access to network capacity in the core zone involves all three non-firm generators, as such NF1 and NF2 are involved in 2 principles-of-access. NF3 connected before NF2 and therefore has higher priority in the core zone principle-of-access. When generation is constrained to manage the core zone constraint the priority order is now NF1; NF3, and NF2.

5.3.1 Curtailment example and demand flexibility in Active Network Management

Using the Zone 1 thermal constraint as an example, and assuming that network losses are negligible. Figure 2 shows the process of calculating curtailment over 4 time-steps. Network capacity consists of export capacity and local demand. Where available wind generation exceeds network capacity, all generation (when stacked in order of priority) beyond the network capacity is curtailed.

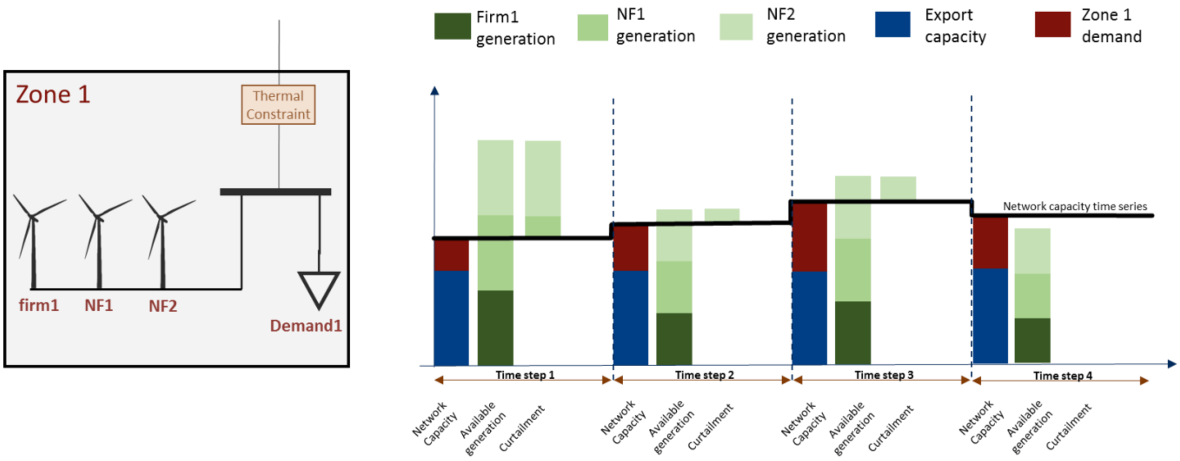

Figure 2: Example of curtailment analysis for Zone 1. Network capacity is the sum of fixed export capacity and varying zone demand. Curtailment is applied using LIFO priority order with generator NF1 given high priority and generator NF2 given low priority. Curtailment is applied during time-steps 1 – 3 but is not required in time-step 4.

During time-step 1, generator NF2 is fully curtailed and NF1 is partially curtailed; during time-steps 2 and 3, NF2 is partially curtailed and NF1 is uncurtailed. This highlights the concept of the 'marginal generator' in standard LIFO arrangements. In time-step 1, NF1 is the marginal generator in that it benefits from a marginal increase in network capacity whilst generator NF2 remains fully curtailed. In time-steps 2 and 3, generators NF2 is the marginal generator.

Connecting new electrical demand within zone 1 will increase network capacity during all time-steps that the new electrical demand is active. Flexibility provided by existing electrical demand manifests as increases in network capacity during some time-steps and decreases at other time-steps. In the 4 time-step example above, the overall optimal solution would be to reduce demand slightly during time-step 4 and re-distributed that demand during time-steps 1 – 3. The timing of that re-distribution can affect which generator benefits: during time-step 2 only NF2 will benefit, during time-step 1, either NF1 or NF2 may benefit. Under standard LIFO an increase in demand during a time-step will benefit the marginal generator, so redistributing demand from time-step 4 to time-step 1 will benefit NF1 whilst redistributing it to time-step 2 or 3 will benefit NF2.

6 COMMERCIAL AND REGULATORY ARRANGEMENTS

The relationship between demand and generation requires commercial arrangements, and both the commercial and physical connections must fit within the current UK regulatory environment. This section highlights the main commercial and regulatory issues that must be addressed in setting up and operating a DES.

Commercial arrangements between generators, supply companies and demand customers are a matter for the open market and do not directly involve DNOs. The role of the DNO is to provide network access under existing rules to both the generators and the demand customers; they are able to charge Use of System Charges either directly to generators and demand customers or via the supply companies. The development of DESs is likely to involve both novel commercial arrangements and to the need to investigate existing connection rules in light of the regulation.

6.1 COMMERCIAL ARRANGEMENT

The objective of a DES is to provide a method of increasing the return for generators and demand customers compared to standard arrangements. These benefits have been discussed in Section 3. There are a number of potential models depending on the proximity of DG and demand, the size of the proposed DES and the method of connection.

6.1.1 Co-ownership of demand and distributed generation

For generation and demand on the same site, ownership of the generator by the demand allows an organisation to directly benefit from its output through a reduction in imported energy and therefore bills. A reduction in import will also result in a reduced Use of System Charges, part of which are calculated based on per unit of imported and exported electricity.

For community scale generation, the price of generated electricity is defined so that it reflects FITs tariffs, even if that generation is used onsite. Therefore every unit of generated power that is used onsite provides an additional income in terms of FITs payments as well as reduced bills.

6.1.2 Direct rebate arrangements between generators and demand

Where generation and demand are separately owned and separately connected to the distribution network, directly trading electricity between the two will normally require the involvement of a supply company (these options are discussed below in Section 6.1.3). However, a simple method of reimbursing demand for providing flexibility outside of existing supply arrangements is through a rebate method. Under this arrangement, generation would ask for an increase in demand at times when this will reduce its curtailment. The generator will benefit from this through increased revenue under its existing PPA and increased payments through government subsidies. If demand is accurately metered, and the variation in demand can be calculated against a baseline, the size of the curtailment reduction can also be calculated. The generator then pays a rebate representing an agreed percentage of its additional revenue.

In this case an important aspect of the scheme will be to define the ‘base case’ against which curtailment reduction will be defined. If flexibility of demand is used, the definition of a base-line against which to compare may be difficult to determine.

The advantage of rebate arrangements is that neither the demand nor generator require to change their suppliers, in fact the scheme does not depend on demand customers having any particular supplier. Demand must fit an additional ‘smart meter’ as well as the supplier’s meter.

6.1.3 Local supply companies

A local small supply company can purchase generation from DGs and sells to the demand. The supply company can also be responsible for buying additional top up energy from the market and selling excess generation to the market. Supply is usually a licensed activity, although there are exemptions available, particularly for very small suppliers. The three options for a local organisation to become a supply company are: fully licensed, licence-lite or licence exempt.

Fully licensed supply company

A fully licensed supply company must fully comply with all the supply licence conditions[9]. This includes compliance with a number of industry codes including the Master Registration Document and the Balancing and Settlement Code. The codes impose expensive IT responsibilities, credit risk and technical challenges well beyond the capacity of a small organisation.

As such it is not expected that a local supply company will be in a position to become a fully licensed supply company.

Licence-lite Supply Company

To reduce the cost of market entry for small suppliers, the regulator has recently amended the supply conditions to allow a supply company to pass its obligations onto a fully licensed supplier. The local supply company effectively contracts to a fully licensed services such as metering, balancing and settlement. This significantly reduces the risk and costs of gaining a supply licence. However, to date the model is untested. Greater London Authority are currently going through the process of applying for a licence-lite supply licence.

As the method is untested, it is expected that the licence-lite route will not be taken by organisations under ARC within the given time-scales.

Licence exempt supply companies

A number of exemptions from the need to hold a supply licence exist. Particularly important for potential DES schemes under ARC is the exemption issued to schemes where the total peak demand supplied is less than 5MW, of which no more than 2.5MW is to domestic customers. This can allow schemes of up to 1000 houses and significant small business demand to operate under a licence exemption. This is a ‘class’ exemption meaning that any scheme which meets the requirement is covered by the exemption without a need to apply for it. There remains a need to contract with a fully licensed supplier to provide services such as metering and balancing. However this route provides a relatively cheap way for small schemes to operate as suppliers of electricity.

It should be noted that if demand is supplied across a private, on-site, distribution network there is the need to operate under an exemption from a distribution licence. This restricts distribution to less than 1MW.

6.1.4 Sleeving agreements

In the past few years a number of organisations have reported the use of third party direct PPAs between generators and end-users of power. The driving force behind this arrangement for larger projects is the fact that standard long term PPA agreements give a relatively low energy price to the generators. Providers of PPAs are not prepared to take significant risk associated with fluctuations in energy price over long periods. From the perspective of large scale end-users of electricity, such direct

[9] https://www.ofgem.gov.uk/licences-codes-and-standards/licences/licence-conditions

agreements provide a level of tractability in their electricity supply not available when purchasing through a supplier.

Sleeving agreements still require a licensed supplier able to take responsibility for balancing and settlement. One briefing note listed two models[10] for this: (i) a 'contract for difference (CfD) approach' with a standard PPA between generator and Supply Company and (ii) standard supply agreement between supply company and demand customer. The generator and demand customer then sign a CfD or "Price Guarantee Agreement" to fix the effective price.

The first of these models is similar to the rebate model described above, with the generators and consumers using standard contracts and signing an additional contract between themselves selves to settle differences.

The literature available suggests that the demand customer will need a 'sizable supply requirement' for this to be beneficial. It will allow the consumer to reduce the risk associated with future energy price fluctuations while providing the generator with more favourable terms[11]. This is important as in general there has been a reduction in the availability of PPA offers given to small independently owned generators and those that are given often do not provide the required level of 'bankability'[12].

Sleeving agreements involving generators outside of the FITS scheme allow the generators to raise the price per unit from a relatively low baseline. However, FIT generators have guaranteed prices significantly higher than those available on the open market. This reduces the prospect of further benefit to generators of entering into sleeving agreements.

6.2 REGULATORY ISSUES

The energy regulator, Ofgem, is tasked with promoting the interested of energy consumers through promoting value for money, security of supply. As such it sets certain rules on various organisations within the electricity sector which dictate how they operate and what obligations they need to comply with. Important regulatory issues are explained below.

6.2.1 Licence exempt distribution

If electricity is to be supplied across a privately owned distribution infrastructure, the owner of the distribution equipment must operate it either under a distribution licence or a distribution licence exemption. This is lower than the limit on licence exempt supply and will limit the size of the scheme to no more than 1MW in total.

6.2.2 The requirements to allow change of supplier

An important principle of the liberalised retail energy market is that consumers are free to change suppliers within 21 days. A recent ruling by the European Court of Justice has made clear that even owners of private distribution networks must ensure that customers connected to their network can change suppliers if they request to do so.

This introduces uncertainty for small supply companies where each individual demand customer represents a significant proportion of their customer base. However, in the case of DES involving curtailment it is likely that a local supply company can offer a significantly reduced tariff to its customers therefore providing a strong hold.

[10] http://www.burges-salmon.com/Sectors/energy_and_utilities/Publications/Direct_PPA_update_November_2011.pdf
[11] http://www.inhouselawyer.co.uk/index.php/environment/8127-on-site-renewable-energy-generation-ten-considerations
[12] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/224081/baringa_ppa_market_liquidity_call_for_evidence.pdf

7 EXAMPLES OF DESIGN ARCHITECTURES

The issues reviewed in sections 3 – 6 identified important considerations for the design of systems coupling demand and generation at distribution level. DESs must be technically feasible, operate securely with robust fail-safe mechanisms, and satisfy the regulatory and commercial environments of the UK electricity sector.

There are a wide range of architectures which can achieve these objectives depending on the type of demand, locations of generators, whether curtailment is an issue, and the operation of ANM if linked to the scheme. This section presents four such architectures. The architectures have been chosen to represent solutions which fit the types of project likely to be developed in ARC including the modelling activities of University of Strathclyde. They offer options which are feasible for ANM and non-ANM connected generators, existing or new electrical demand, and flexible or inflexible demand.

Each of the four architectures represents a technical solution, and within each architecture there is room for several commercial models. Figure 3 shows the four technical options discussed and some commercial complexities associated with each.

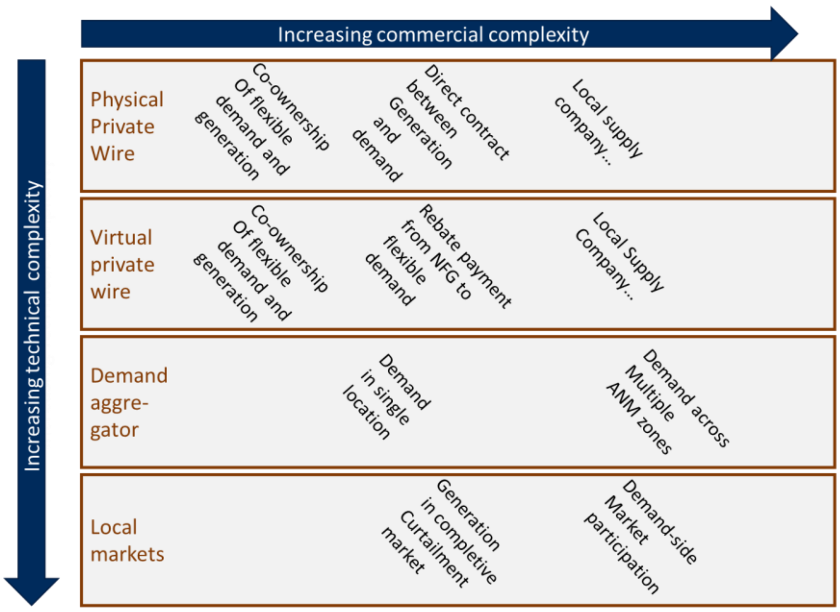

Figure 3: The key options for connecting flexible demand as part of an ANM scheme to support non-firm generators

Physical Private Wire systems represent an existing tried and tested solution for DES schemes. Virtual Private Wire solutions are technically feasible but rarely been deployed. Demand Aggregator schemes have received a large amount of academic interest and a number of trial projects have been rolled out around the world, including the NINES project on Shetland. Finally Local Markets are complex solutions which require significant change to the current operating philosophy of UK distribution networks.

In addition to the information in this section, the appendix to this document (Page 41) presents system flow diagrams for examples of each of the architectures showing the relationships between trading and monetary flows, physical electricity flows and information flows.

7.1 PRIVATE WIRE SYSTEMS

A private wire (PW) system is a localised private electricity network that directly connects demand and generation. It can be seen as a micro grid that supplies domestic customers and businesses. Its size can range from single sites to urban area or housing development. The DG is located either on the same site as the demand, or a geographically close site and the two are directly connected via the private wire network. The entire PW network is connected to the distribution network via a single point-of-connection.

The DG capacity within a PW network can be larger or smaller than demand with the difference between the two being imported or exported through the point of connection with the distribution network.

The export capacity of a PW system can potentially receive any of the connections available to stand-alone generators: firm connection, export limited, or a non-firm connection under an ANM scheme. Under export limited and ANM connections a local controller is used to control DG and demand on the PW network and make sure that the PW system export capacity not exceeds the distribution network constraints.

7.1.1 Physical description of the system

The electrical components which form part of the PW system are:

- Electrical generator
- Connection equipment for electrical generation
- Electrical demand
- Connection equipment for electrical demand
- Private network of overhead lines and cables
- Switch/interface between PW and public network

If the PW system has an export limited connection or a non-firm ANM connection, a controller is required to manage export. For ANM it must adjust the power injection of the PW system within the set-point limits defined by the ANM scheme. For example, if there is surplus power, the PW controller must either curtail the generation or increase flexible demand.

Since the private wire system is independent of the distribution network operator, distribution use of system charges will be reduced as there is a reduction of import. In some cases, if demand receives a supply from both the private wire and the distribution network, customers may have a switch them to manually revert to the distribution network.

A schematic diagram of a PW system operating within an ANM scheme is shown in Figure 4. It shows the ANM scheme linked to the local controller of a PW system. The ANM scheme monitors the power flow through the export meter.

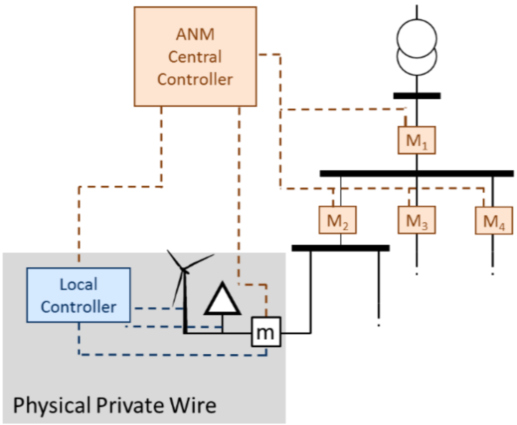

Figure 4: Schematic of a Private Wire System

7.1.2 Commercial arrangements

Co-ownership of distributed generation and demand

A PW scheme with DG and demand under the same ownership does not need further commercial arrangement. A contract is signed with a supplier who will pay DG and export at the relevant FITS rates and change import on a standard tariff. The co-owner of demand and generation benefit from FITS payments and reduced requirement to import. Demand can operate as fixed, or be managed in a flexible way to minimise import or reduce curtailment.

If demand and generation are separately owned an arrangement is needed between the two parties.

Direct contract between generator and demand customer

For small systems, a simple contractual arrangement between the generator and demand is possible as the system will operate under exemptions from the electricity supply licence conditions. This arrangement can be a private agreement between the owner of the generation and the demand customer. Alternatively a local supply company can be set up as an intermediately (see Virtual Private Wire network below).

7.1.3 Case Studies

Applecross hydro and heat scheme

A hydro-electric generation scheme on Applecross in the north-west Highlands has been proposed, initially with a 99kW generator limited to 90kW by the DNO. Applecross Community Company (ACC) is investigating the possibility of installing a larger hydro turbine and using excess generation for producing heat to the buildings over private wire. Several options are in consideration and the most cost effective and efficient solution may be to install a single large turbine which will supply both private wire consumers and the 90kW export limit to the grid.

Vatersay wind powered district heating

Vatersay Council, a small island in the Western Isles, is considers an option of installing wind turbines on a constrained grid connection in order to provide electricity to a district heating scheme supply. The grid connection is limited as the island does not benefit from a three phase supply. The scheme involves linking wind turbines to electric storage heater with a private wire network. The private wire system will distribute electrical heat to all properties with heating controllers in each property as well as a control system within the village.

Findhorn Eco-village

The village of Findhorn is served by a privately owned distribution network connecting domestic and small commercial properties as well as a small wind farm. Findhorn is located in the north of Scotland, an area served by Scottish Hydro Power Distribution as the DNO. The Findhorn Foundation acts as a local supply company and customers connected to Findhorn’s private distribution network can be supplied with electricity by the Findhorn foundation. Flow into and out of Findhorn is monitored as the interface with the public distribution network.

7.2 VIRTUAL PRIVATE WIRE

A virtual private wire (VPW) system consists of demand and generation connected at different points to the distribution network and power flowing between them across the distribution network. The VPW can be characterised by its net contribution to a distribution constraint in a similar way to a physical private wire. The maximum export of a VPW can be limited at a level below the installed DG capacity or managed through an ANM scheme, in the same way as a physical private wire system. The difference between the two architectures is that power flows between demand and generation across the distribution network rather than through a private network. The section of distribution network involved in these internal VPW flows is below any network constraint locations.

In an ANM scheme a VPW network can interact as a single entity with the ability to interpret a single ANM set-point by either reducing generation or increasing demand to produce the same aggregate result.

7.2.1 Description of the system

A VPW makes use of the existing power system infrastructure avoiding duplication. The important aspects of such a scheme are the monitoring and control components. Figure 5 shows a schematic for a VPW operating within a subsection of a distribution network with ANM. The demand is located outside the wind farm meter, although the communications and control architecture are almost identical to that shown in Figure 4. The ANM scheme is linked to the controller of a VPW and monitors power flow through the meters of generation and demand.

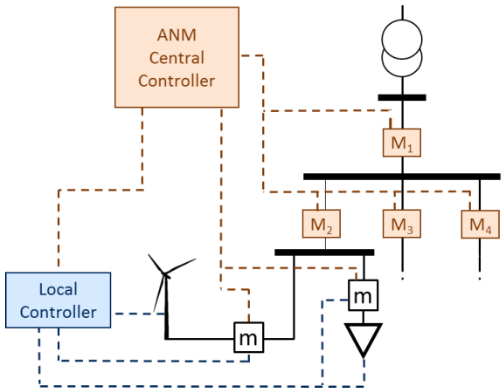

Figure 5: Schematic of a Virtual Private Wire System with an ANM scheme

The VPW system connects DG and demand via the existing distribution network. As such the components which form part of the power-transfer part of the VPW are:

- Electrical generator
- Connection equipment for electrical generation
- Electric demand
- Connection equipment for electrical demand
- DNO owned overhead lines, cables, transformers linking the generator and demand

A VPW is to be seen by the wider distribution network and an ANM scheme as a single entity with a single power injection. The DNO will stipulate the point at which the virtual net injection of power are calculated for, this may be the relevant constraint location, or the point at which power flows from and to the generator and demand converge.

In the case of an export limited connection, the net export of the VPW is limited below the capacity of generation. A control system similar to that for a Private Wire system must be in place to increase demand or curtail generation if export approaches the limit. This controller monitors generation and demand on the VPW and ensures that the combined virtual injection is maintained within limits.

In the case of ANM the VPW controller can report the aggregate power injection to the ANM scheme, or the ANM scheme may choose to monitor each of the VPW assets individually and carry out its own aggregation calculation.

If the demand and DG assets are separated by significant electrical impedance electrical losses between the two need to be considered when calculating the net contribution to a constraint. Calculating the true virtual power injection of the VPW in this case depends on other power flows through the DNO network as electrical losses depend on *total* power flow. In this case the internal VPW controller requires either a direct real-time measurement of power flow or can use the 'worst case' losses.

Interaction with Active Network Management Scheme

The inclusion of a VPW in an ANM scheme raises a number of technical challenges for the ANM operator and the design of the VPW. These relate to the interpretation of ANM signals and the required response time for curtailment.

The provision of set-points by the ANM scheme to a VPW can be achieved in the same way as for non-firm generators: a single set-point is sent and interpreted as relating to net power injection rather than generator output.

In the event that the VPW fails to comply with a set-point within the specified time-frame, the ANM scheme will wish to trip the generator assets of the VPW; demand assets should be left connected. This requires a direct communication link between the ANM scheme and the breakers at the DG assets.

The ANM scheme will monitor the net power injection of the VPW. This can be achieved in two ways.

- Allow the VPW to report its net power injection directly to the ANM scheme. This requires a high level of confidence in the ability the VPW controller to correctly calculate and communicate the Aggregate Power Injection.
- Monitor the power injection of all generators and power offtakes of all demands in the VPW network individually and perform a calculation of the net power Injection within the ANM. This gives greater certainty to the ANM operator of the robustness of the calculation, although at the expense of more communication and monitoring.

Active Network Management actions are triggered at particular values of power system variables (power flow or voltage) set below the absolute limit. One consideration for demand flexibility within an ANM scheme is the timescale of response. Generators are given a particular time to respond to a trim set-point within ANM. If a VPW (or a physical private wire) intends to use demand response to decrease net export, the time-scale of demand response must be considered.

7.2.2 Commercial arrangements

The commercial arrangements for a VPW system will be significantly more complex than those for a physical private wire. Electricity flows across the distribution network, and such a scheme will need an organisation operating as a supplier to take ownership of the electricity on the distribution network. For community schemes it is likely that a small supply company will quality for a supply licence exemption assuming the DES is small, although there is still a need to contract out for metering and balancing services to a fully licensed supply company.

Two potential commercial arrangement frameworks are presented here which can be deployed. The operation of a VPW will entail a range of regulatory issues.

Rebate Arrangement

Most generators and demand customers contract with an energy supplier to buy and sell electricity. Distributed generators are likely to sign Power Purchase Agreements (PPAs) in which they will receive a specified price in pence per MWh over the lifetime of the agreement. Demand customers will sign a contract either with a single fixed price of electricity or a time-dependent price.

A rebate arrangement maintains the existing contracts for both generators and loads, and allows an *ex-ante* calculation of the additional generation and therefore generator revenue facilitated by demand flexibility. The generator and demand customers within the VPW can agree how to split the additional revenue with the mechanism being a rebate paid directed from the generator to the loads.

As all VPW assets remain contracted to their existing energy supplier, the existing arrangements for Distribution Use of System charges are maintained and the retailers maintain their responsibilities under balancing and settlement.

The rebate arrangement is simple and cheap administer. An important issue is calculating the level of generation that would be achieved without the response of flexible demand. If flexible demand is *only* operated to reduce generator curtailment this is simple, but if demand customers will draw electricity anyway and it is the timing of that demand that is adjusted due to generator curtailment; a clear counterfactual demand profile is required against which to compare the response.

Local Supply Company

A second commercial option is for a local supply company to be set up. This supply company will buy the output of generators and sell electricity to flexible demand customers.

The exact arrangements for such a company may vary. For example the local supply company can:

- buy all the output from generators, sell to demand and sells net export to a large retailer;
- supply all electricity to customers and buys shortfalls from large retailers; and
- buy only the additional generation facilitated by electrical generators and sell only this electricity to flexible customers

In any of these cases, the most likely option is for the local supply company to operate as a licence exempt supplier (see section 6) if it's total peak demand is less than 2.5MW for domestic demand and 5MW for total demand[13]. The benefit of licence exemption is to relieve suppliers covered by an exemption from many of the obligations enacted by the standard electricity licence conditions including adherence to the balancing and settlement code. There remain requirements on licence exempt supplier, for example to contract with a licensed supply company to provide services such as balancing. The local supply company contacts to buy generation and sell to consumers. Consumers pay the local supply company which pay the generators. The local supply company contract with a licensed supplier for example for balancing services and the local supply company pays the DNO for distribution use of system charges.

[13] http://www.legislation.gov.uk/uksi/2001/3270/schedule/4/made

7.2.3 Case studies

Virtual private wire systems are rare in the UK with DNOs general unwilling to facilitate them. One DES set up by Woking Council includes physical and virtual private wires as well as the provision of heat to commercial customers from CHP plant.

Woking Borough Council[14]

Woking Council runs a distributed energy scheme linking renewable and CHP generation with demand in council premises, local commercial buildings, and social housing. The scheme involves a number of components including private electrical wires, private district heating network and some provision of electricity to social housing around the town via the public distribution network. This final component forms a VPW system and makes use of the local distribution network owned and operated by UK Power Distribution.

[14] http://www.woking.gov.uk/environment/climate/Greeninitiatives/sustainablewoking
John P. Thorp and Lara Curran; Affordable and Sustainable Energy in the Borough of Woking in the United Kingdom Bulletin of Science, Technology & Society April 2009 29: 159-163, doi:10.1177/0270467608331186

7.3 Demand aggregation

Domestic consumers and small businesses can, in aggregation, provide a significant level of demand flexibility. Accessing this demand means communicating and controlling a large number of small demands in a coordinated way. A DNO or an ANM scheme operator is unlikely to have the capacity to communicate directly with each demand, and generators will not want to make separate arrangements with a large number of households. In addition, variations in individual loads are often difficult to predict whereas useful flexibility emerges from the statistic effect of aggregated demand.

In schemes involving a local supply company, the supplier may acts as an aggregator if it supplies to a large number of small loads. A non-firm generator informs the local supply company of a curtailment event, and the supply company creates an increase in demand which reduces the curtailment.

However, there may be situations in which demand is not aligned with one particular generator. There are a number of options for such schemes. The DNO or ANM can consider incorporating demand within an ANM scheme, or the DNO may instigate a scheme which facilitates supply companies setting up ‘flexible tariffs’ based on information provided by ANM.

A second option is that demand makes its flexibility available to multiple generators. For example in an ANM scheme under existing LIFO principles of access, flexible demand could offer its flexibility to whichever generator is currently the marginal generator.

The management of multiple small demands in either of these situations can be organised by a demand aggregator. The aggregator acts as a single point-of-contact for other actors within the distribution environment: ANM operators, DNOs, and generators.

7.3.1 Physical description of the system

A demand aggregator system makes use of the existing electrical network to supply electricity to the consumers, in the same way as is done at present. The innovation of an aggregation scheme is to allow the manipulation of many existing (and new) electrical demands through the current electrical infrastructure. Aggregation requires the roll out of smart meters to all demand customers to provide an accurate record of the timing at which demand is taken and allow the calculation of the flexibility provided by each individual load.

With smart meters installed for all customers, the basic communication and control actions of the aggregator are shown in Figure 6. The aggregator monitors the current demand of each individual customer and aggregates this to give a total demand. It receives a set-point demand level from an external system, this can be a generator or the ANM system for example. The aggregator uses some control algorithm to calculate how to meet the set-point and send control signals out to individual customer’s premises.

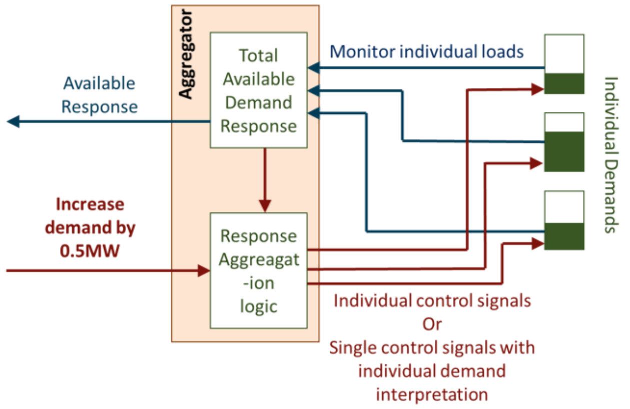

Figure 6: Schematic representation of an aggregator

Demand aggregated to assist in the management of a particular constraint must be behind that constraint. Demand aggregators may contract with demand across more than one ANM zone, however in this case demand in each zone must be treated separately.

7.3.2 Commercial arrangements

A demand aggregator arrangement is needed when demand flexibility is provided by small individual demands, and the demand flexibility is not associated with a particular generator. Here it is assumed that a demand aggregator is being operated on a network managed by ANM. The commercial arrangements relating to the aggregator depend on the particular arrangements allowed within the ARC project. Two examples are given here.

Arrangements with a single generator

An aggregator contracts with a generator and agrees a price per unit of otherwise curtailed energy that the demand flexibility facilitates generation of. A contract can be relatively short term allowing the aggregator to renegotiate prices as other generators join an ANM scheme or change to working with a different generator. The method of payment could be through a rebate paid by the generator to the aggregator, or through the aggregator acting as a supply company (most likely through the licensed exempt route).

Arrangements with multiple generators facilitated by ANM

The demand flexibility can be controlled by the ANM scheme using demand set-points. The ANM system calculated a demand set point for the aggregated demand according to a clearly defined principle which aims to help achieve the ANM objectives (for example maximising renewable generation). The demand aggregator receives and implements the demand set-point across its portfolio. Post-operation, a calculation is run using a baseline demand profile to calculate the increase in generation from each non-firm generator due to the demand flexibility. Generators pay a proportion of the additional revenue to the aggregator which distributed this among its customers. This scheme requires that generators agree at the time of signing up to ANM to make payments to demand in this way.

There are a number of other possible commercial arrangements depending on the rules chosen for Active Network Management.

7.3.3 Case studies

Demand aggregation has been trialled as part of a number of projects.

Northern Isles New Energy Solutions Project[15]

The Northern Isles New Energy Solutions Project (NINES) on Shetland uses demand aggregation to manage electric storage heaters across the Islands power system. For the past 20 years storage heaters on the Islands have been controlled via a radio teleswitching system with fixed on and off times which remain the same. The NINES project has introduced modern storage heaters through its Domestic Demand Side Management project. The aggregator receives an ideal profile from the Shetland ANM scheme for the draw of electrical power by the storage heater fleet. The profile is calculated from wind DG and fixed electrical demand forecasts and is designed to minimise the curtailment of wind and minimise the variability imposed on fossil-fuel generation. The demand aggregator splits the ANM profiles across its portfolio and individual heaters implement this profile. However, heaters are programmed to maintain a number of consumer comfort and security limits which take priority over the daily profile and can lead to variations from the scheduled profile.

Demand Side Response in the Domestic Sector – a literature review of major trials[16]

The Department of energy and Climate Change commissioned a detailed literature review of demand side response trials. The resulting report identifies several ways in which demand response is being harnessed. Key tariff structures include: time of use tariffs with prices varying across the day; Critical Peak Pricing where significantly higher prices are introduced on a small number of days to manage peak demand; and Critical Peak Rebates where customers are reimbursed for reducing demand during peak periods.

The case-studies identified use a range of enabling technologies such as in home displays, ‘energy orbs’ and programmable thermostats. The review notes the importance of automation in ensuring that demand response is reliable and continues.

[15] http://www.ninessmartgrid.co.uk/
Dolan, M. J.; Gill, S.; Ault, G. W.; Barnacle, M.; Bell, G.; Foote. C.; "Modelling and delivery of an active network management scheme for the Northern Isles new energy solutions project," *CIRED,* Stockholm, June 2013.

[16] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48552/5756-demand-side-response-in-the-domestic-sector-a-lit.pdf

7.4 LOCAL MARKETS

A local market is a mechanism in which both non-firm generators and flexible demand units take part via offers and bids in the buying and selling of electricity. It allows consumers to buy electricity from local producers and the local market operator to balance the system in order to satisfy both demand and generation needs whilst maintaining network constraints.

The market price will be influenced by the weather, price of fuel and emission allowances. The local market can interact with an ANM scheme through market operator.

One example of a local market is a curtailment market: under this arrangement, the existing ANM principles of access are applied to calculate initial curtailment levels. Then curtailed generators and flexible demand submit offers and bids for increased generation and increased demand respectively. A local market operator then clears the market, and passes the reduced curtailment levels to the ANM scheme for implementation.

7.4.1 Physical description of the system

A schematic of a local curtailment market system operating with an ANM scheme is shown in Figure 7. It shows the ANM scheme linked to the local controller that controls non-firm generators and demands.

The ANM scheme monitors power flow through the meters of generation and demands. Demands are spread across the distribution network and are not associated with a particular generator. They can be monitored individually via demand meters or aggregated via load aggregator that controls a group of demands.

The market mechanism has a close-to-real-time price signal which acts as a balancing method for managing distribution congestion. There is a clearing period, after which the local market operator clears the market and sends results to the ANM scheme for implementation. A price signal close to real-time minimizes forecast errors caused by volatile outputs of renewable resources.

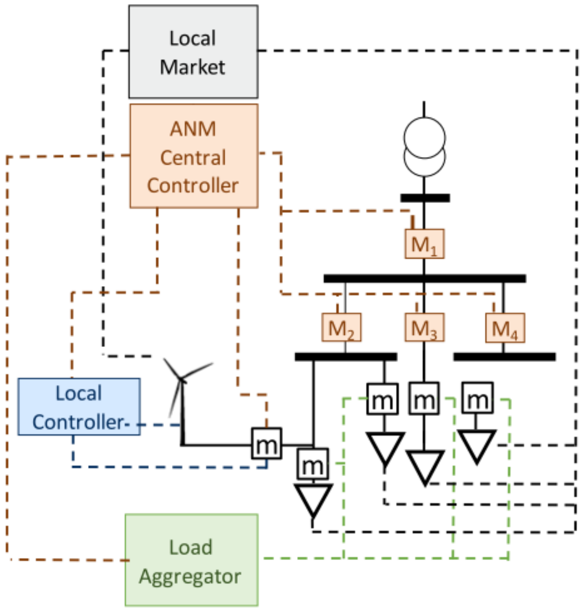

Figure 7: Schematic of a Local Market System

The power transfer components of the network remain unchanged. The market operator requires communications infrastructure between itself and participants in the market. This allows participants to place bids and offers and the market operator to inform the results of market clearing. The control aspect of the market involves implementing the cleared market: sending and maintaining set points for generators and loads. This can be achieved through an ANM scheme.

7.4.2 Commercial arrangements

The commercial arrangements for a market system can be potentially complex. One method is for fixed demand to continue to buy electricity via their usual suppliers and generators to sell uncurtailed generation to suppliers under their existing PPA. Then addition generation facilitated the demand flexibility is traded through the local market operator. Flexible demands pays the market operator which in turn pays the generator for the additional generation at the market clearing price. Although there are several commercial arrangement frameworks for a local market mechanism, one presented here include demand participation via load aggregator.

7.4.3 Case studies

Olympic Peninsula[17]

A price-responsive electricity market with 5-minute clearing intervals for additional generation has been implemented in the Olympic Peninsula, Washington State, USA. Energy-management systems enable two-way communication between the grid and distributed resources in order to avoid the network congestion in the peak time.

Demand side of the market submits bids for power to be used in the next 5-minute period. Usually, two bids are submitted, one for controllable loads that can be curtailed and the other bid for uncontrollable loads that is always infinity from the market perspective.

[17] http://www.pnl.gov/main/publications/external/technical_reports/PNNL-17167.pdf

There are two options for submitting bids on the supply side. If a generator is able to run in parallel with the power grid, it submits offers for the maximum power that it can produce. The offer includes fuel cost, start-up, early shut-down penalty, operation and maintenance cost, and licence usage premium[18]. On the other hand, if a generator is not able to generate back into the distribution network, it is considered as a backup generator and submits bid as a consumer, on the demand side of the market.

If the feeder into Olympic Peninsular is not congested, the local price is same as the wholesale price. When this is not a case, the local price rises above the wholesale price.

EcoGrid EU[19]

The EcoGrid EU project is located on the Danish island of Bornholm. It investigates how information and communication technology and an extension of the current market solution can increase the utilization of renewable energy sources within the power systems. It makes use of flexible electricity consumption through heat pumps, electric heating, and electric vehicles. The market operates separately from the Nordic wholesale market and has a 5-minute settlement period. The price is set close-to-real-time to minimise the errors associated with wind generation predictions. It is based on a 'bid-less' system which means that customers and generators need to respond to a centrally defined market price rather appearing as the outcome of an auction. This method also allows locational pricing to manage congestion.

The project involves 2000 participants, 1900 households and 100 industrial/commercial buildings. The households are divided into three groups: statistical control group, manual control group, and automatic control group with IBM/Greenwave and Siemens/SyncoLiving home automation system. The industrial/commercial buildings have Siemens automation systems.

The ICT platform consists of 2 components:

1. A price generation model which takes input from TSO, electricity spot market, historical metering data, and weather forecasts.
2. Price distribution components which broadcast price information to the customers via Internet Service Providers.

[18] Licence usage premium allocates and manages the number of hours when a generator can be active and running.
[19] http://www.eu-ecogrid.net/

8 POTENTIAL ARC PROJECTS

This section identifies a number of potential demand related projects in the ARC area. A long list of potential projects is still being assessed and further projects may come to light in the course of the ARC project. These represent the most advanced project opportunities to date, although further external dependencies (such as planning permission) may limit the actual scope for their inclusion. Where applicable, the options from Section 7 that are most likely to be suitable for each project have been indicated.

- **Dunbar Demand Side Management:** Sustaining Dunbar is willing to work with householders and large energy users in the town to provide a flexible load for a demand-side management scheme that would allow local DG capacity to export at times when it would otherwise be constrained. Details to be confirmed. This project would be suitable for a demand aggregator solution.

- **Standhill Anaerobic Digester:** A 195kWe Anaerobic Digester plant is being built at Standhill Dairy Farm situated at the end of a long, rural line that suffers from voltage issues. Following a more detailed analysis, 153 kVA export onto the line has been offered. Possibilities to improve this connection include dynamic line rating and flexible load on Standhill and other nearby farms. The project would be suitable for a Physical or Virtual Private Wire solution.

- **Yetholm Joint Venture wind and Demand Side Management:** A farmer near the town of Yetholm has developed a wind turbine project in close discussion with the local Community Council. Although an earlier planning application was turned down, a new application for a smaller turbine has been submitted and residents in the town may be willing to investigate the possibility of a Demand Side Management scheme to use surplus generation. This project may be suitable for a virtual private wire system with new electrical demand, or a combination of a Virtual Private Wire and demand aggregator scheme with existing domestic demand.

- **Drysdale wind turbine**: There is the possibility of a medium sized wind generation scheme west of Coldingham. Details to be confirmed.

- **Circuit 120-21:** There are currently at least four wind turbine applications that are looking to connect to this long, rural, voltage-constrained line from the Primary Substation at Ayton near Eyemouth. There may be possibilities to set up a Demand Side Management scheme with some of the nearby villages. No discussions have yet taken place.

9 CONCLUSIONS

This report has presented an overview of the issues associated with coupling demand and DG under the ARC project to mitigate curtailment of renewable generators. It discusses the benefits of such schemes for the generator and demand customers, and the regulatory difficulties associated with setting up such schemes.

ARC will include an ANM scheme and it is likely that generators connected under ANM which are expecting to experience significant curtailment will be interested in linking with demand. Other generators may also want to link with demand, particularly generators being offered firm generation connection that are smaller than the proposed DG capacity.

The report notes that regulation on the distribution and supply of electricity are a significant barrier to the development of small schemes, particularly where those scheme make use of the network owned by a DNO to transfer electricity between DG and demand.

The type of demand coupled to DG will significantly affect the design of any scheme. For example, where demand is flexible or uncontrolled, new or existing electrical demand, and the geographical location of demand and DG.

The report provides four example architectures which may be relevant to ARC: physical private wires, virtual private wires, demand aggregators, and local markets.

- **Physical Private Wires** are likely to be the most effective way of linking demand and DG if the two are on the same site, or geographically very close.
- **Virtual Private Wires** are likely to be the most effective way of linking demand and DG if the two are further apart, as long as both are connected behind the same network constraint. DNOs have been reticent about implementing virtual private wire schemes to date, however a well-designed scheme can meet the security requirement of a DNO whilst reducing the need for unnecessary extra infrastructure.
- **Demand aggregators** are required if a large number of small demand customers are keen to participate in a smart distribution network, but without a link to a particular generator.
- **Local Markets** at distribution level have been facilitated outside the UK and represent a potentially powerful solution, however the complexity and relative novelty of such as scheme is likely to be such as require its own project.

APPENDIX: SYSTEM-FLOW DIAGRAMS FOR THE PROPOSED DESIGN ARCHITECTURES

This appendix gives representations of the various flows involved in potential DES schemes involved in ARC. Five 'flows' are used to describe the organisation of these schemes:

- **Energy trading flows:** Energy is traded, brought or sold between organisations. The trading of energy does not necessarily reflect the physical flows of power across an electricity network however it links generators to supply companies and demand customers.

- **Payments of monetary flows:** Closely linked to the concept of energy trading are the monetary flows associated with payments. Payments are made for energy and for other services such as Use of System.

- Electricity flows: Electricity flows represent the physical flow of power, and are determined by the laws of physics rather than economics. Electricity flows from generators across networks and to demand customers.

- Monitoring data flows: The deployment of ANM requires an increase in the flow of information. Monitoring data represents information that is collected remotely and used to make decisions of control actions.

- Control data flows: Control data represents the flow of instructions from one entity to another requiring action.

A.1 SYMBOL KEY

The symbols used in this appendix are defined in the key below (Figure 8).

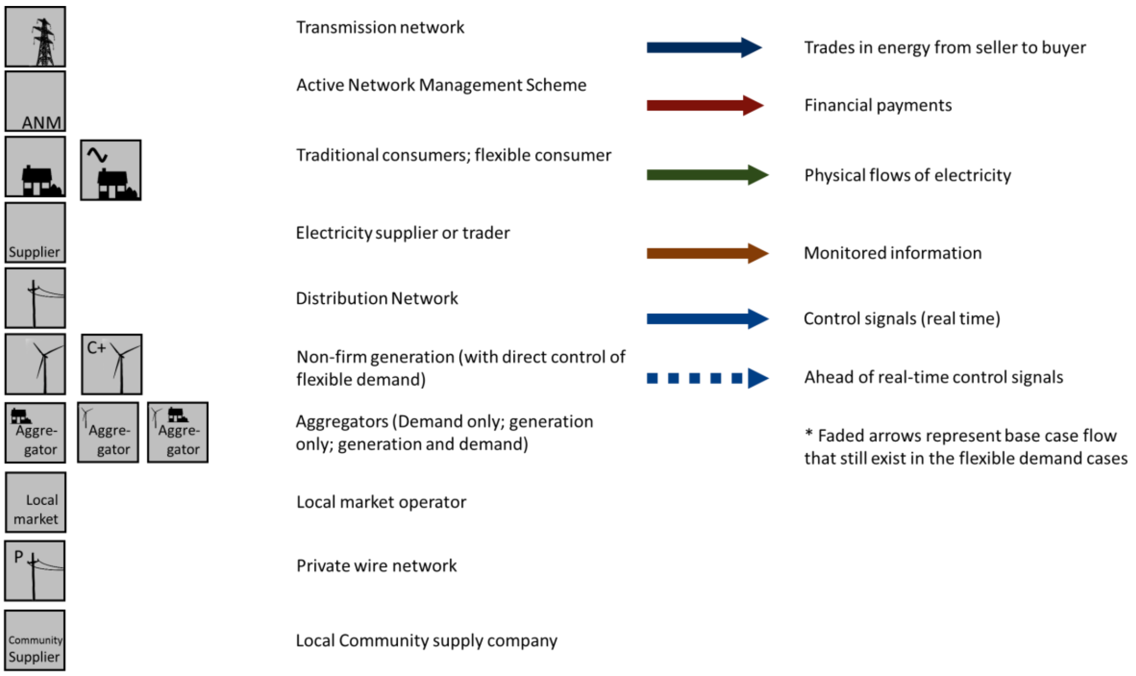

Figure 8: Symbols for use in system flow diagrams

A.2 Base Case – Existing ANM schemes

The base-case scenario is assumed to be an ANM scheme with no flexible demand. Firm and non-firm generation is connected to the distribution network, and ANM monitors the network and generator outputs and instructs curtailment when required. Commercial arrangements for non-firm generators and demand customers go through the usual large supply company route. The flows are shown below in Figure 9.

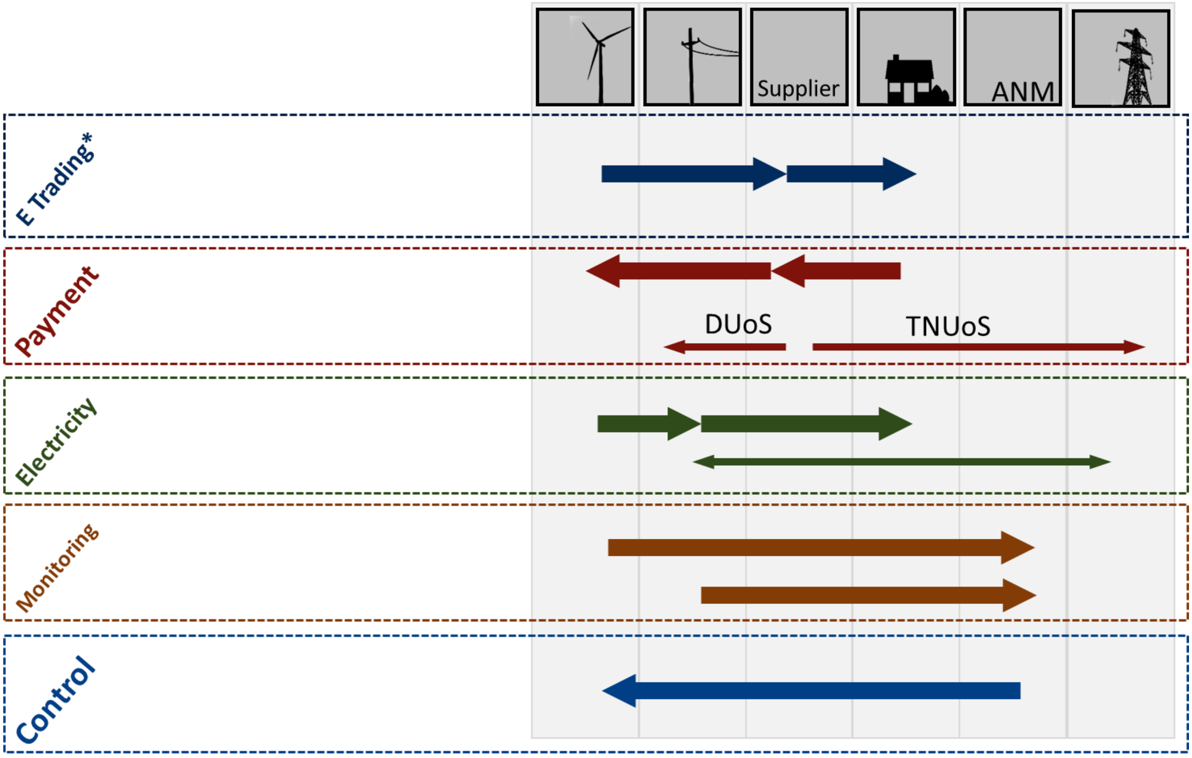

Figure 9: System flows for the base-case of an existing ANM scheme with no demand flexibility and no DES

A.3 BEHIND THE METER

A behind-the-meter or private wire based DES allows private commercial arrangements to be made between generator and demand. In this example illustrated below, a non-firm generator installs a controller which allows it to instruct flexible demand behind-the-meter to increase demand to reduce curtailment. Network flows for this scenario are shown below in Figure 10.

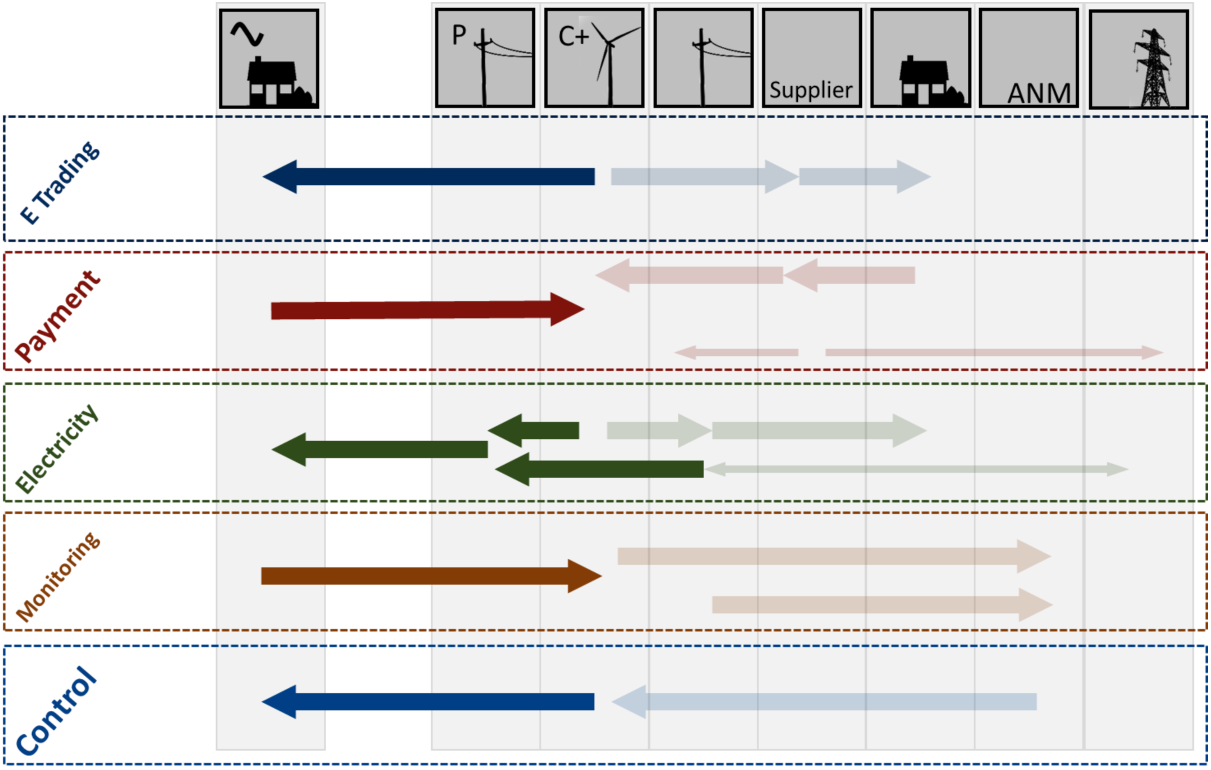

Figure 10: System flows for the case of a DES operating behind-the-meter with private arrangements between generator and associated demand.

The base-case flows are shown as faded arrows and these flows continue to occur. The solid arrows represent additional flows required by the operation of the DES. The flexible demand on the left hand side represents only the flexible part of load.

Some electricity is now sold privately from the generator to the behind-the-meter flexible demand with payment being made from flexible demand to generator. This electricity flows over private network assets, with additional 'top-up' electricity being supplied from the public network.

The ANM scheme continues to monitor, and apply limits to the export of the DES, and the local controller at the non-firm generator acts within these constraints to vary demand or curtail generation.

A.4 Virtual Private Wire with Rebate

The virtual private wire arrangements means that power continues to flow between generation and demand across the DNO network. In the diagram below, Figure 11, the flexible demand which forms part of a DES is separated out from the fixed demand but continues to be purchased from a supply company in the standard way. It is the *ex-ante* rebate payments from generator to the flexible demand that shares the benefit of increased renewable generation between generator and demand.

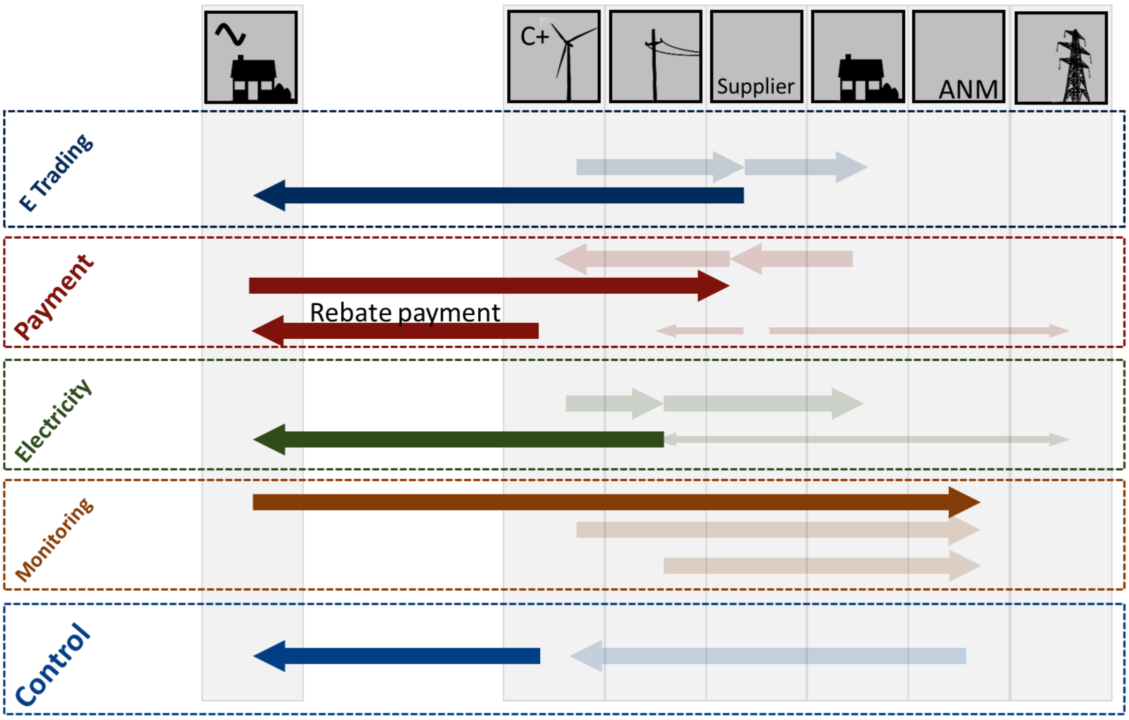

Figure 11: System flows for a virtual private wire systems with rebate payments for increased generation paid ex-ante from generation to associated demand.

The faded arrows again represent the base case flows. Initially energy trades and payments flows between demand, suppler and generator are conducted in the normal way and the additional rebate payment flow is added later.

In this example the ANM scheme treats the net of generation and demand within the DES as the value against which to apply limits. To achieve this flexible demand is monitored and netted against the monitored value of generation giving the net injection of the DES; in this example this calculation is carried out in the ANM central controller. As with the behind the meter option the non-firm generator includes a controller which can vary demand or curtail generation in response to ANM control signals.

A.5 Virtual Private Wire with Local Supply Company

The use of a Local Supply Company removes the need for the rebate payment. In this option, the non-firm generator sells some of its generation directly to the local supply company which sells onto the flexible demand customers. In addition, the local supply company pays Use of System Charges to the DNO and pays the large supply company for the provision of balancing services etc. as required under a supply licence exemption. Network flows for this scenario are shown below in Figure 12.

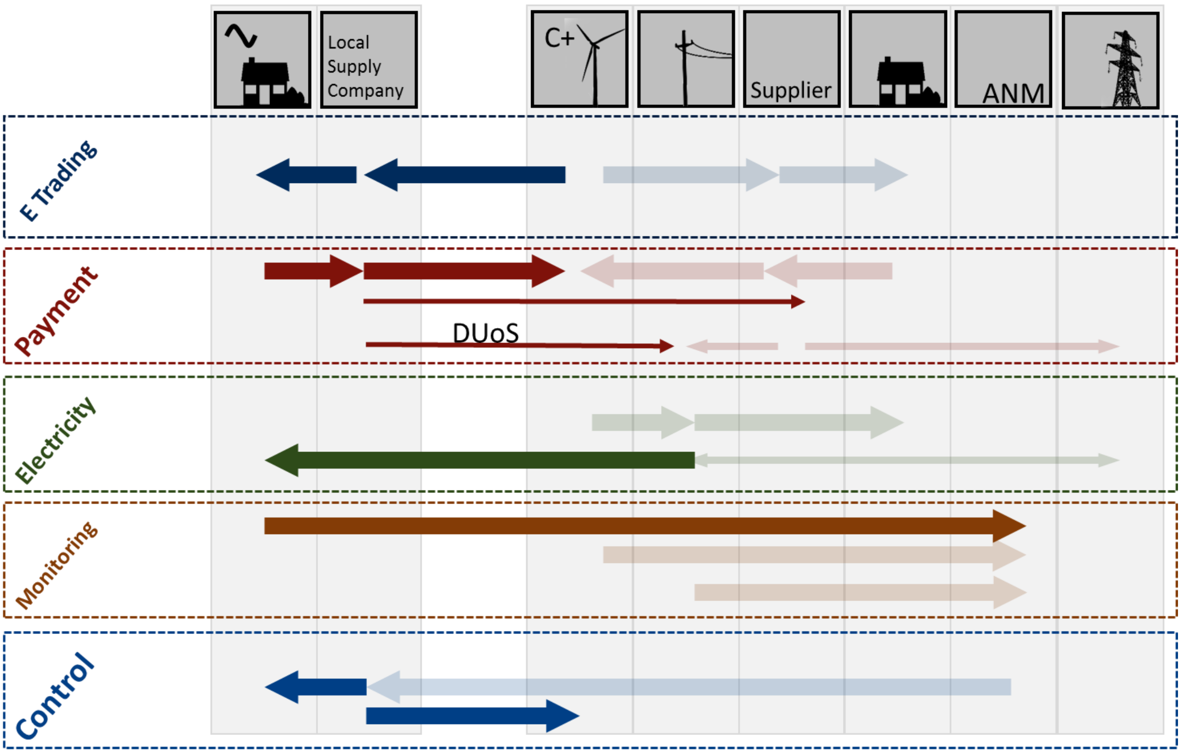

Figure 12: System flows for a virtual private wire in which DES energy is supplied by a local supply company.

There is little change in terms of the monitoring and control of the system compared to the rebate payment example shown in Figure 11. However, the ANM control signal is now received, interpreted and acted on by the Local Supply Company rather than by the generators control system. The local supply company becomes the point-of-contact for the DES.

A.6 Demand Aggregator

Under a demand aggregator arrangement a number of different models are possible as discussed in Section 4. Here one model is presented where the aggregator offers demand flexibility to the marginal generation in a LIFO based ANM scheme. Demand customers continue to purchase electricity from their usual supply company. The demand aggregator offers upwards flexibility to various generators when that generator is marginal in terms of curtailment. *Ex-ante* the generator makes a payment to the aggregator which distributes the payment among its participants in line with their response. The system flows are shown below in Figure 13.

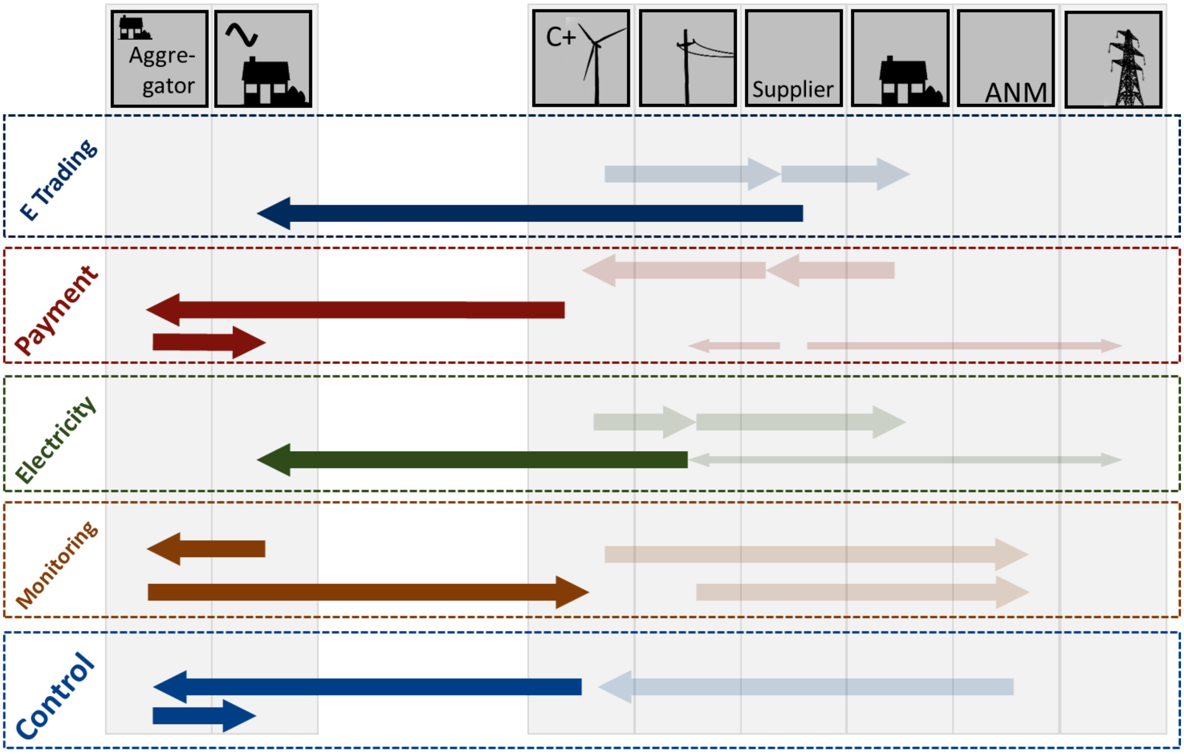

Figure 13: System flows for a demand aggregation scheme where the demand aggregator offers flexibility to the marginal non-firm generator.

As the scheme continues to operate as a LIFO only scheme, the ANM scheme has no requirement to measure demand. The only necessary change is the ANM scheme provides a clear indication to generators when they are marginal. However, on when marginal a generator will wish to send a control instruction to the aggregator and will wish to verify the response of demand through monitoring. The monitoring and control arrangements are similar to those associated with the VPW using a rebate payment as shown in Figure 11.

A.7 Local Market

The local market option involves the greatest number of system flows, however it should be remembered that whilst the trading and information flows are more complex the flows of electricity remain very similar to the other options.

In the example below in Figure 14, a local market is set up for curtailment reduction. An initial calculation is carried out to give the expected curtailment levels of each non-firm generator according to a LIFO priority order. Generators are allowed to output the amounts defined in this calculation in the usual way and are likely to sell under a standard PPA to a large supply company.

Generators can then offer additional generation, that is 'otherwise curtailed generation' to the local market. Demand customers, via aggregators can bid to make use of that additional generation. The local market operator receives the bids and offers, clears the market and calculates the additional generation and expected demand levels of each participant. This information is passed to the ANM central controller which uses its communications network to provide updated set points to generation and to demand aggregation.

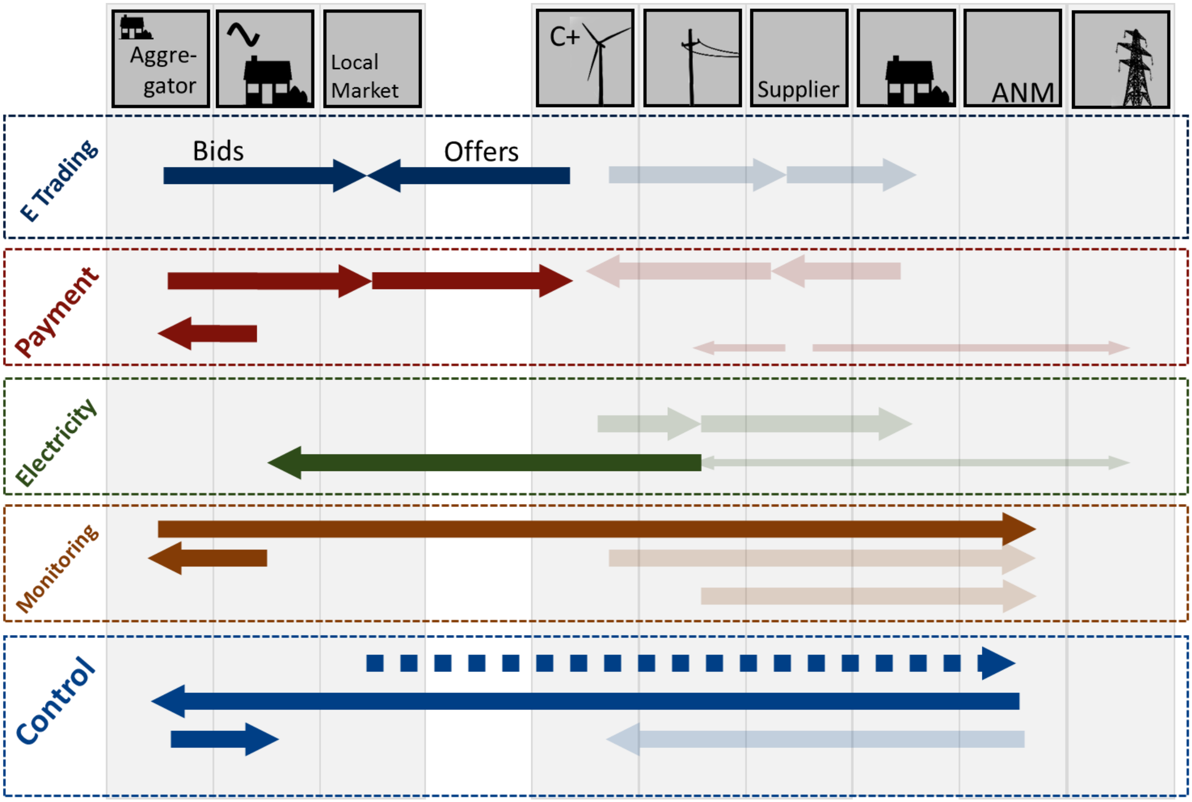

Figure 14: System flows for a local curtailment market. The local market operator receives bids and offers for a settlement period in the near future (for example, the next 5 minutes). On clearing the market and defining final generation and demand it passes this information to the ANM central controller ahead of real time. The ANM central controller then issues set points to all ANM connected devices.