HubNet Position Paper Series

Smart metering for the development and operation of the GB power system

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About HubNet

HubNet is a consortium of researchers from eight universities (Imperial College and the universities of Bristol, Cardiff, Manchester, Nottingham, Southampton, Strathclyde and Warwick) tasked with coordinating research in energy networks in the UK. HubNet is funded by the Energy Programme of Research Councils UK under grant number EP/I013636/1.

This hub will provide research leadership in the field through the publication of in-depth position papers written by leaders in the field and the organisation of workshops and other mechanisms for the exchange of ideas between researchers and between researchers, industry and the public sector.

HubNet also aims to spur the development of innovative solutions by sponsoring speculative research. The activities of the members of the hub will focus on seven areas that have been identified as key to the development of future energy networks:

- Design of smart grids, in particular the application of communication technologies to the operation of electricity networks and the harnessing of the demand-side for the control and optimisation of the power system.
- Development of a mega-grid that would link the UK's energy network to renewable energy sources off shore, across Europe and beyond.
- Research on how new materials (such as nano-composites, ceramic composites and graphene-based materials) can be used to design power equipment that are more efficient and more compact.
- Progress the use of power electronics in electricity systems though fundamental work on semiconductor materials and power converter design.
- Development of new techniques to study the interaction between multiple energy vectors and optimally coordinate the planning and operation of energy networks under uncertainty.
- Management of transition assets: while a significant amount of new network equipment will need to be installed in the coming decades, this new construction is dwarfed by the existing asset base.
- Energy storage: determining how and where storage brings value to operation of an electricity grid and determining technology-neutral specification targets for the development of grid scale energy storage.

The HubNet Association is a free-to-join grouping of researchers and research users. Join via the "HubNet Registration" tab at www.hubnet.org.uk to get access to working document versions of positions papers, an archive of workshop and symposium presentations and to receive notification of future events.

Contents

This position paper follows a symposium held at Cardiff University on 18th-19th September 2013 as part of the HubNet programme. The symposium was organised by Dr Tracy Sweet of Cardiff University, the programme can be found on the HubNet website. The paper also follows a previous HubNet position paper, Smart Metering for the UK [1].

1 Introduction

Smart metering is one of a growing number of data gathering systems associated with the GB power system. The Department of Energy and Climate Change (DECC) identifies smart metering as "a key enabler of the future Smart Grid" [2], the aim being to achieve the following:

- Decarbonising the electricity system through increasing connection of renewable generation and decentralised generation
- Improving asset utilisation
- Providing decision making support to engineers (in both operation and planning)
- Maintaining system stability and security of supply

It is expected that these goals will be achieved through a more closely monitored and controlled power system. Increased control of frequency, voltage, power flows and fault levels throughout the network will be required. To improve control of these quantities, the quality of input information must first be enhanced. It is anticipated that the forthcoming GB smart metering system (expected to be completed in 2020 [3]) will form part of the collection and feedback of information needed to achieve this.

Demand Response is expected to contribute to achieving three of the above goals [4][5] (decarbonising the electricity system, improving asset utilisation, and maintaining stability and security). The present proposals indicate that the GB smart metering system will be able to support demand response in a number of ways; through variable pricing (to an half hourly granularity), control of demand[1] and supply disconnection/re-enablement[2].

Many new automated data and information flows, between the main actors operating and planning the electricity network, are expected to be established over the coming decades. As the LV system is presently largely devoid of automated data collection, the GB smart metering system represents a significant change. This change is illustrated in Figures 1 and 2. There is a challenge to the industry in adapting practices to accommodate, and make use of, the new data.

[1] Smart meters will be able to read status of and send commands to up to 5 HAN (Home Area Network) connected auxiliary load control switches. They will also be able to store a set of up to 200 switching rules, based on price level, in a 'calendar' [6].

[2] Operated on receipt of command or based on a configurable active power 'load-limit'. This seems to be targeted at payment protection, although it has not been ruled out for use in demand response schemes.

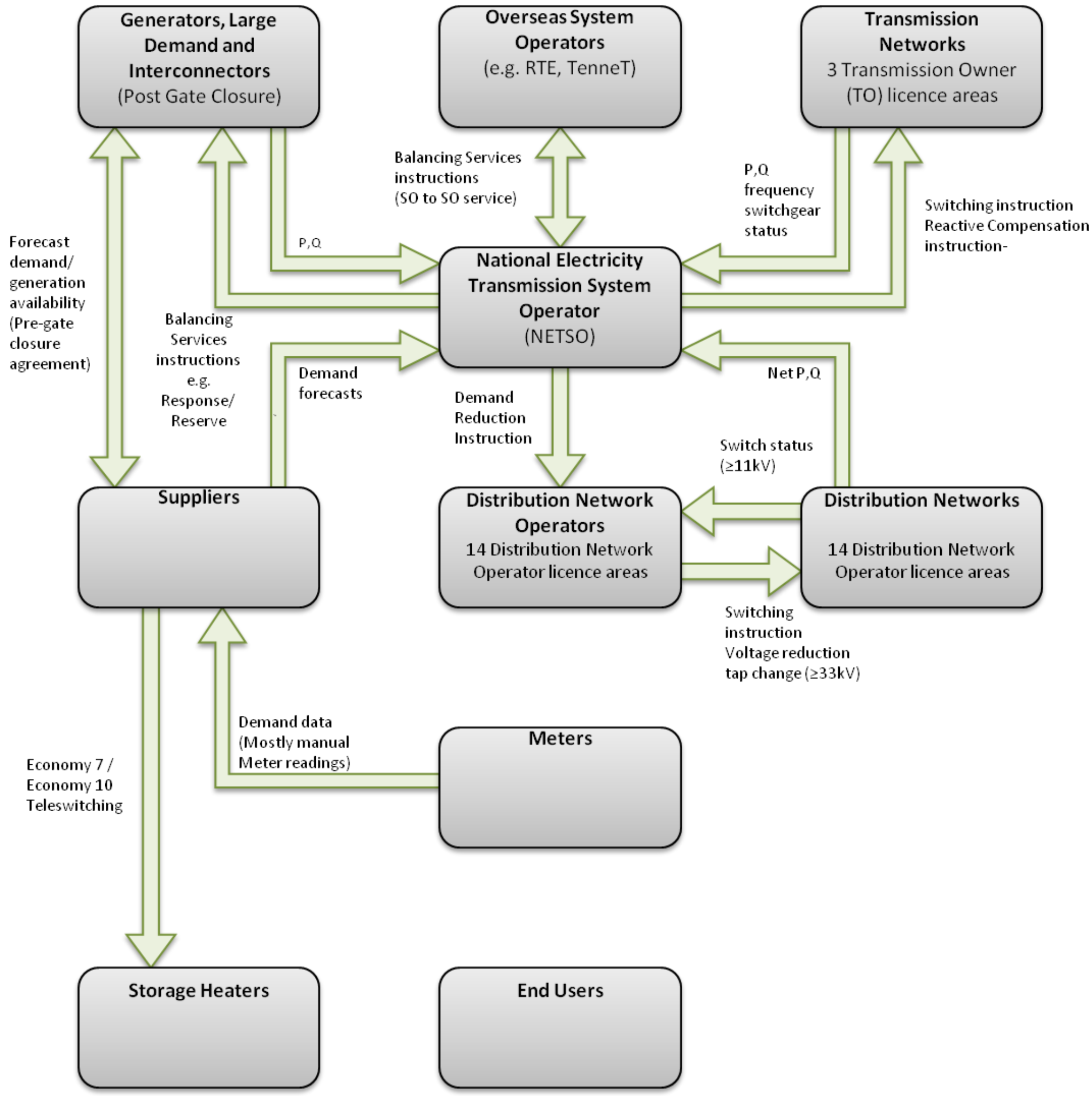

Figure 1 - NOW - Information Flows for GB Electricity Network Operation - as prepared by the author of this Position Paper for the IET PNJV [7].

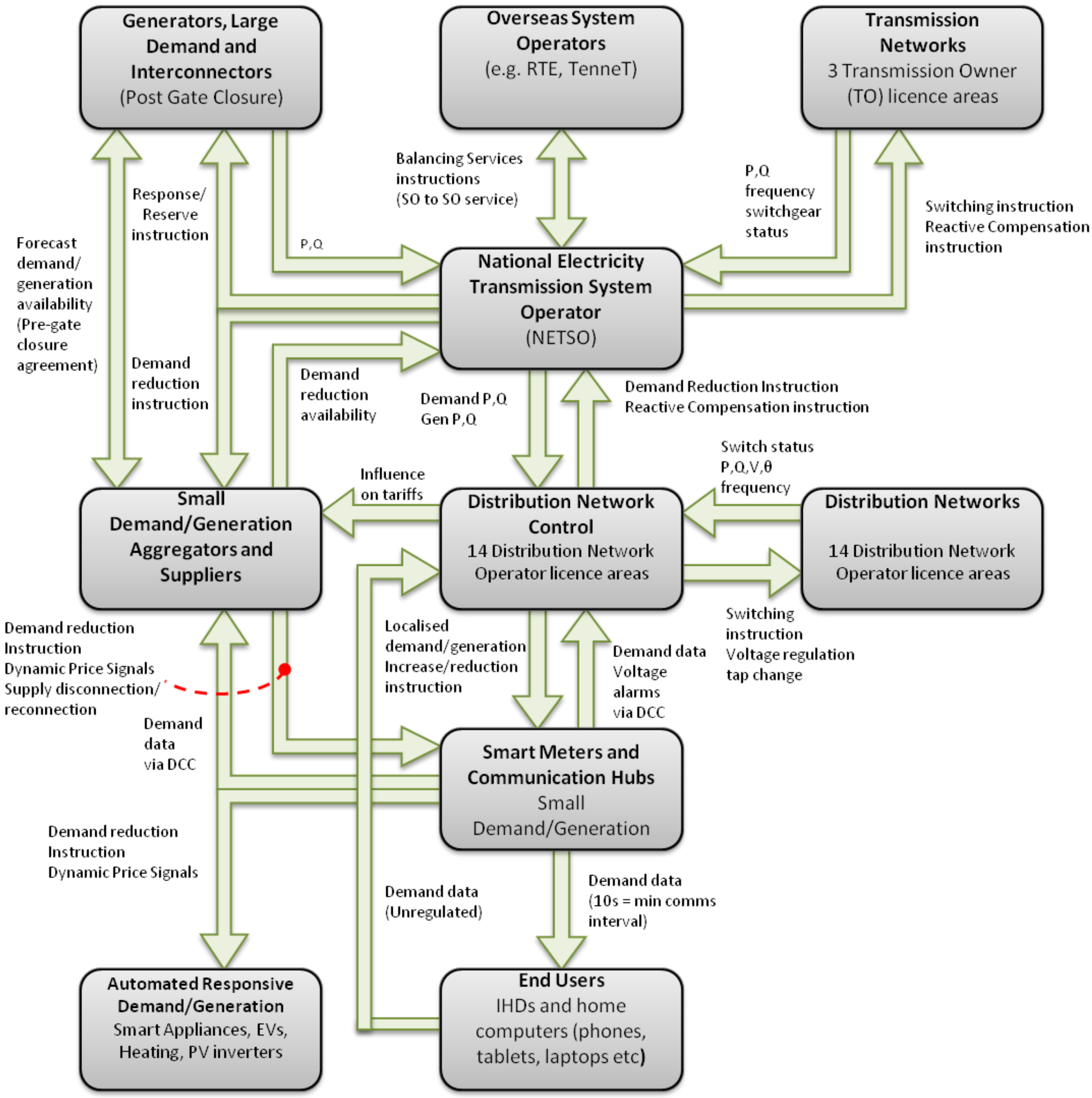

Figure 2 – NEXT – Possible Information Flows for the GB Electricity Network Operation following the Smart Meter Roll Out and increased levels of distributed generation- as prepared by the author of this Position Paper for the IET PNJV [7].

2 Smart metering and smart grid research activity in the UK

Use of smart meter data, for the operation and planning of the GB power system, is the subject of ongoing research, development and demonstration [8][9]. Publicly funded research in academia is supported by institutions including EPSRC (Engineering and Physical Sciences Research Council), TSB (Technology Strategy Board), ESRC (Economic and Social Research Council) and the European Commission's FP7 (Framework Programme 7). Much of the research in the area falls within the category of Smart grids – which itself is typically found under the theme of Energy.

Following the £500 million LCNF (Low Carbon Network Fund) funding initiative from OFGEM (Office for Gas and Electricity Markets) in 2011, network operators have begun demonstration projects to prove the benefit of smart grid technologies [10]. Figure 3 compares the 2013 annual budget of the LCNF with various funding bodies' 2013 energy theme allocation.

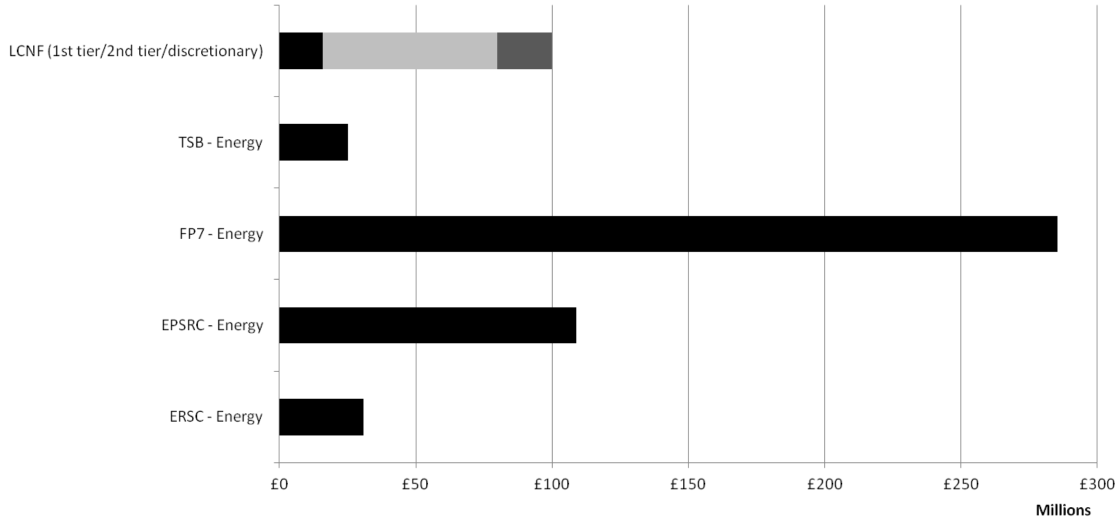

Figure 3 – 2013 annual research budgets in the Energy theme from various funding bodies and OFGEM [10][11][12][13][14]. Note – shown FP7 budget assumes total budget is spread evenly over 7 years.

Output from academic research is usually disseminated in journals and at conferences. Ten journals likely to publish on the topic of using smart meter data for operation and planning are shown in Table 1. They are ranked in order of SCImago's Journal Rank Indicator [15]. The journals have been selected from the field of power engineering and smart grids. Relevant research may also be published in other areas, such as data informatics or electronics.

	Title	SJR	H index	Total Docs. (2012)	Cites / Doc. (2years)	Country
1	IEEE Transactions on Smart Grid	3.035	25	248	13.49	United States
2	IEEE Transactions on Power Systems	2.837	129	422	5.26	United States
3	IEEE Transactions on Power Delivery	1.922	95	294	3.14	United States
4	Electric Power Systems Research	1.781	54	223	2.73	Netherlands
5	International Journal of Electrical Power and Energy Systems	1.671	48	378	4.48	United Kingdom
6	IET Generation, Transmission and Distribution	1.541	56	100	2.33	United Kingdom
7	IET Electric Power Applications	1.304	56	79	2.37	United Kingdom
8	IEEE Power and Energy Magazine	1.185	41	71	3.42	United States
9	Power System Technology	0.579	30	552	1.28	China
10	European Transactions on Electrical Power	0.576	18	188	0.96	United Kingdom

Table 1 – A selection of academic journals that disseminate smart grids research. Information obtained from [16]

In traditional publishing business models, academic research is published in journals that require fees to be paid for future access. This can be restrictive to those who are not supported by institutions that are prepared to pay journal access fees. As a result, the use and dissemination of research is restricted. There is pressure to move away from this model towards open access publishing – so that academic output is free (gratis and without restriction on use and re-distribution) [17][18]. The UK government has announced that “it will make publicly funded scientific research available for anyone to read for free.” [19]

Output from the LCNF projects is disseminated via ENA’s (Energy Networks Association) smarter networks portal [20] and at the annual LCNF conference. The output takes the form of reports and presentations. It is not known whether the raw data (e.g. monitored data in the network monitoring category) and network configurations will be made available to third parties. Such data may allow researchers or businesses to experiment and prove ideas.

Forums for discussion and dissemination of international research, on smart metering for electricity networks, include:

- ISGT (Innovative Smart Grid Technologies) conferences (Europe, America, Asia), run by the IEEE (Institute of Electrical and Electronics Engineers)
- CIGRE (Conseil International Des Grands Reseaux Electriques) Sessions
- CIRED (Congrès International des Réseaux Electriques de Distribution) Workshops
- IET Events

In the UK, the main forums include:

- The Annual LCNF conferences [21]
- HubNet Symposia
- IET events
- UKERC Workshops

3 The Data Communications Company (DCC) and the Smart Energy Code

Figure 4 shows an overview of the proposed smart metering system. A central component of the system is the Data Communications Company (DCC). The DCC has responsibility for the communication of smart meter data and the presentation of the data to DCC "Users" (e.g. Suppliers, DNOs[3]). The interface between the DCC and the Users will be known as the User Gateway. It is proposed that "DCC Service Users will communicate with the DCC via a series of 'Service Requests' and the DCC will respond via a series of 'Service Responses'. In addition, Service Users may receive 'Alerts' from the DCC." [22]

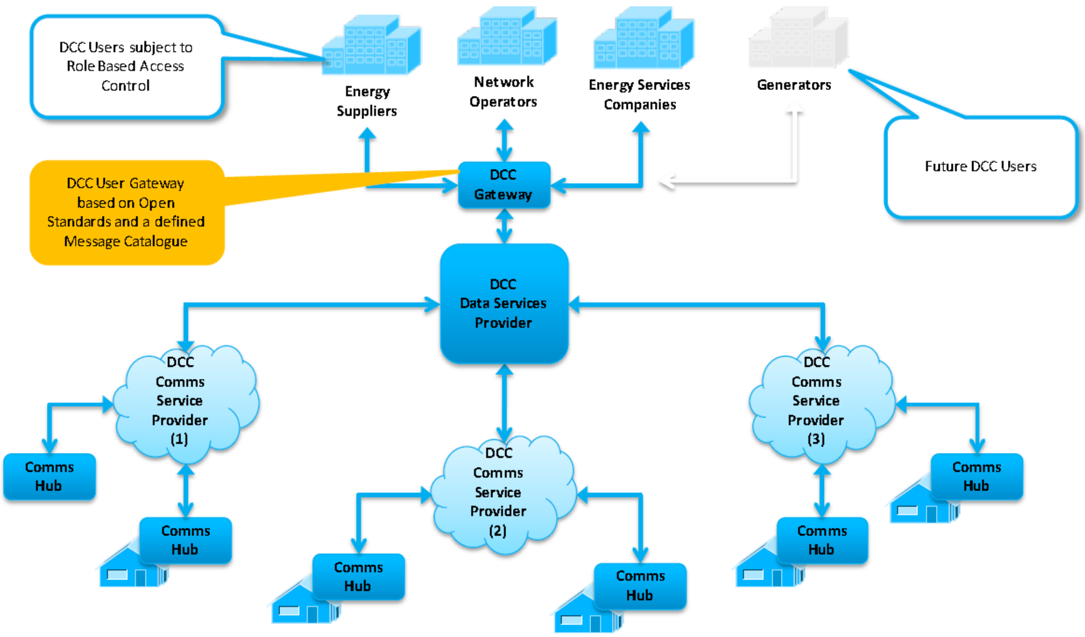

Figure 4 - Overview of the proposed end-to-end smart metering infrastructure, taken from [23]

The DCC licence has been awarded to Capita's SmartDCC Ltd. The DCC has agreed sub-contracts for the Data Service Provider (CGI IT UK Ltd) and the Communications Service Providers; divided into North (Arquiva Smart Metering UK Ltd), Centre and South (both Telefonica UK Ltd). Gemserv Ltd has been awarded the role of Smart Energy Code Administration and Secretariat (SECAS) and will develop and maintain the Smart Energy Code over a four year contract[24].

Governance of the GB smart metering system will be achieved through the Smart Energy Code (SEC). The SEC is a self governed multiparty contract "which sets out the terms for the provision of the DCC's Smart Meter communications services, and specifies other provisions to govern the end-to-end management of Smart Metering." [25] It is being introduced in stages, see Table 2. The DCC, Suppliers and Network Operators are required by licence to comply with the provisions of the SEC.

[3] DNOs – Distribution Network Operators – Licensed operators of the distribution network (0.4 to 132kV)

SEC Stage	Areas Covered	Status (June 2014)
Stage 1 (SEC1)	Initial operations of the Data Communications Company (DCC) (e.g. Charging Methodology)	Came into effect September 2013
Stage 2 (SEC2)	Connection to and Use of the DCC User Gateway Requesting DCC's Services Service and Incident Management Establishment of a Technical Subcommittee	Initial Consultation – October 2013 Government Response – January 2014
Stage 3 (SEC3)	Introduction of SMKI (Smart Metering Key Infrastructure),	Initial Consultation – December 2013 Government Response – March 2014 (Part A), June 2014(Part B)
Stage 4 (SEC4)	Foundation Meters Communications Hub Services Security and SMKI	Consultation expected "summer 2014"

Table 2 - Smart Energy Code development progress [25][26][27]

As part of the Smart Energy Code, two documents are under development - the DCC User Gateway Interface Specification (DUGIS) and the DCC User Gateway Code of Connection (DIG CoCo). These will govern the use of the DCC User Gateway. The SEC2 consultation document [22] includes a list of proposed "user services" to be provided by the DCC (where the users include suppliers and network operators). There are two categories of service; "future dated" (available within 24 hours of a service request) and "on demand" (available within 30 seconds of a service request). A list of all user services proposed for electricity network operators is shown in Table 3. Additionally, there is an "alert" function for messages generated by smart meters. The response time for alerts will be within 60 seconds of "notification of the alert at the communication hub function". The alerts shown in the SEC2 consultation document are listed below:

- Average RMS Voltage above Over Voltage Threshold
- Average RMS Voltage below Under Voltage Threshold
- RMS above Extreme Over Voltage Threshold
- RMS below Extreme Under Voltage Threshold
- RMS above Voltage Swell Threshold
- RMS below Voltage Sag Threshold
- Power Loss
- Supply Outage Restored
- Supply Outage Restored - Outage >= 3 minutes
- Outcome of Ad hoc Change to Home Area Network (HAN) connected Auxiliary Load Control switch
- Outcome of Calendar Based Change to HAN connected Auxiliary Load Control switch
- Supply Armed
- Unauthorised Physical Access
- Trusted Source Authentication Failure
- Not intended recipient of Command
- Source Does not have Permission for Command
- Emergency Credit Available
- Credit Below Low Credit Threshold (prepayment mode)

- Disablement of Supply Suspended
- Credit Below Disablement Threshold (prepayment mode) - Supply Disabled
- Unauthorised Communication Access attempted

Service Name	Description	Future Dated (<24 hrs)	On Demand (<30 secs)
Read Instantaneous Import Registers	Read the specified import register or matrix on a specified meter as soon as the Command is received by the meter.	-	✓
Read Instantaneous Export Registers	Read the specified registers on a specified meter as soon as the Command is received by the meter.	-	✓
Read Profile Data	Return the specified date range of profile data from the profile data log for a specified meter.	✓	✓
Read "Network" Data	Retrieve stored power quality data from a Device for a specified Device ID.	✓	✓
Read Maximum Demand Registers	Retrieve the maximum demand register values recorded on a specified meter.	✓	-
Read Load Limit Counter	Retrieve the specified Load Limit Counter data on the specified meter.	✓	-
Read Active Power Import	Retrieve the specified Active Power Import values on the specified meter.	✓	✓
Retrieve Daily Consumption Log	Retrieve the specified Daily Consumption Log entry(s) on the specified meter.	✓	✓
Read Device Configuration	Retrieve the configuration data values for a specified meter.	-	✓
Update Device Configuration (Voltage)	Configure the voltage thresholds on a specified meter.	✓	✓
Read Event Or Security Log	Retrieve the Event and/or Security logs for a specified meter.	-	✓
Update Security Credentials	Replace the Security Credentials held on the specified Device with the credentials contained with the Service Request.	✓	✓
Set Maximum Demand Registers	To set the maximum demand register value(s) and timeframe on a specified meter.	✓	-
Retrieve Device Security Credentials	Retrieve the public Security Credentials from a specified Device.	✓	✓
Read Supply Status	Return the current supply status at a specified meter.	-	✓
Read Boost Button Details	Retrieve the details of the Boost Button on a specified Device.	✓	✓
Read Firmware Version	To retrieve the firmware details that currently exists on a specified Device.	✓	✓
Device Alert	To send the details of an event generated by a Device to a defined Known Remote Party in the message.	-	✓ (60 secs)
DCC Alert	To send the details of an event in relation to one or more Communication Hub Functions generated by the DCC to the relevant User.	-	✓ (60 secs)

Table 3 – Proposed DCC Service Requests, applicable to electricity network operators, that send commands to devices [25]**(Annex 3)**

Based on the consultation proposals, suppliers will have access to some demand response functions that network operators will not have. The services available to suppliers but not to network operators are shown in Table 4.

Service Name	Description	Future Dated (<24 hrs)	On Demand (<30 secs)
Update Import Tariff	Update the import tariff on a specified meter	✓	✓
Update Import Price	Update the import price on a specified meter	✓	-
Read Tariff	Read the current tariff settings (including price, time of use matrix and time of use blocks) that are in use on a specified meter, in addition to the payment mode status	-	✓
Update Device Configuration (Auxiliary Load Control)	Configure the Auxiliary Load Control calendar and/or description for a specified Device.	✓	✓
Update Device Configuration (Load Limiting)	Configure the load limiting functionality on a specified meter, including, where specified, reset of the Load Limit Counter	✓	✓
Update Device Configuration (Instantaneous Power Threshold)	Configure the ambient power thresholds on a specified meter for display on an IHD.	✓	✓
Enable Supply	Enable electricity/gas supply through a specified meter.	✓	✓
Disable Supply	Disable electricity/gas supply through a specified meter.	-	✓
Activate Auxiliary Load	Activate the specified Auxiliary Load Control Switch (ALCS) for a specified Device.	-	✓
Deactivate Auxiliary Load	Deactivate the specified Auxiliary Load Control Switch (ALCS) for a specified Device.	-	✓
Read Auxiliary Load Control Switch Configuration	Retrieve the configuration information of a specified Auxiliary Load Control Switch (ALCS) for a specified Device.	✓	✓
Reset Auxiliary Load	To reset the specified Auxiliary Load Control Switch for a specified Device.	-	✓
Add Auxiliary Load To Boost Button	Place the Auxiliary Load Control Switch under the control of the Boost button on a specified meter	✓	-
Remove Auxiliary Load From Boost Button	Remove the specified Auxiliary Load Control Switch from the control of the Boost Button on a specified meter	✓	✓
Read Boost Button Details	Retrieve the details of the Boost Button on a specified Device.	✓	✓
Set Randomised Offset Limit	Set the Randomised Offset limit on a specified meter	✓	-
Join Service (Type 1 Devices)	To allow specified Devices to communicate with each other via the HAN	-	✓
Join Service (Type 2 Devices)	To allow a Type 2 device to receive data via the HAN (To be reviewed once the rules on Consumer Access Devices have been further developed).	-	✓

Table 4 – Proposed DCC Service Requests, related to Demand Response, that send commands to devices and are not available to electricity network operators [25]**(Annex 3)**

4 The Smart Metering Equipment Technical Specifications

The Department of Energy and Climate Change (DECC) Smart Metering Equipment Technical Specifications (SMETS) describe the physical, functional, interface requirements of gas smart metering equipment, electricity smart metering equipment and the In Home Display (IHD) for the proposed GB roll-out. The development of the specification can be tracked through documents made available by DECC. The most important documents are listed in Table 5.

Document	By	Description	Date released
Prospectus Consultation: Statement of Design Requirements	DECC/ OFGEM/GEMA	Proposals for delivery of gas and electricity smart metering in "every home in Great Britain".	July 2010
Response to Prospectus Consultation: Statement of Design Requirements – Functional Requirements Catalogue	DECC/ OFGEM	The UK government's response to the July 2010 consultation responses.	March 2011
Industry's Draft Specification	Smart Metering Design Group (SMDG)	A draft specification produced by industry stakeholders follow a review of the March 2011 Functional Requirements.	August 2011
Smart Metering Equipment Technical Specifications "SMETS-1"	DECC	Describes the physical, functional, interface requirements of gas and electricity smart metering equipment and the In Home Display (IHD).	Version1.0 – April 2012 Version 1.1 - September 2012
Consultation on the second version of the Smart Metering Equipment Technical Specifications	DECC	Seeks views on the proposed additional functions and features that to be introduced to an updated version of the SMETS (SMETS 2) – 50 questions.	August 2012
Government Response to the Consultation on the second version of the Smart Metering Equipment Technical Specifications – Part 1	DECC	Addressed 16 of 50 consultation questions.	January 2013
Smart Metering Equipment Technical Specifications Version 2 - "SMETS-2"	DECC	Describes the physical, functional, interface requirements of gas and electricity smart metering equipment and the In Home Display (IHD).	January 2013
Government Response to the Consultation on the second version of the Smart Metering Equipment Technical Specifications – Part 2	DECC	Addressed 34 of 50 consultation questions.	July 2013
Consultation on the process to finalise the Great Britain Companion Specification	DECC	The process for completing the GBCS	February 2014
Government response to the consultation on the process to finalise the Great Britain Companion Specification	DECC	Response to the consultation on the process to finalise the Great Britain Companion Specification	April 2014

Table 5 - Documents tracking the development of the UK government Smart Metering Technical Specifications

There are two main versions of SMETS, known as SMETS-1 and SMETS-2. The majority of installed meters will be compliant with SMETS-2. A second iteration of SMETS-2 is in development along with specifications for the communications hub specifications; the Communication Hub Technical Specification (CHTS) and the Intimate[4] Communications Hub Interface Specification (ICHI / ICHIS), see Table 6.

Document	**By**	**Description**	**Expected** [28]
Communication Hub Technical Specification (CHTS)	DECC	Sets out the minimum physical requirements, minimum functional requirements, minimum interface requirements and minimum data requirements that will apply to a Communications Hub [29].	Q3 2014
GB Companion Specification (GBCS)	DECC and 'industry'	This is the subset of the base specifications for ZigBee SEP and DLMS, which must be used to support the implementation of smart metering in Great Britain. Will set out how the application protocols will be used to deliver the SMETS functionality and include requirements of the Commercial Product Assurance (CPA) regime, covering the security characteristics of devices. [29].	Q3 2014
Second Iteration of the Smart Metering Equipment Technical Specifications Version 2 - "SMETS-2"	DECC	Will include the GBCS and provisions for: • a Pre-Payment Interface Device (PPMID), including the functionality to allow a PPMID to interface with the Home Area Network (HAN); • Auxiliary Load Control switches; • Consumer Access Device (CAD) pairing, including the functionality to allow a device to pair with the Communications Hub locally; and • the use of Unique Transactional Reference Numbers (UTRNs), for use in prepayment should the Wide Area Network (WAN) be unavailable. [29]	Q3 2014
Intimate Communication s Hub Interface Specification (ICHI / ICHIS)	DECC	The ICHI Specification sets out the minimum requirements that will apply to the Intimate Communications Hub interface between the communications hub and the electricity meter [29].	Q3 2014

Table 6 – Expected documents in the development of the UK government Smart Metering Technical Specifications

As the specifications are not yet fully defined, in order to test smart grid applications based on smart metering data input, researchers must make assumptions about smart metering data acquisition and communication constraints. Researchers might also make use of anticipated auxiliary functions. These constraints and functions will depend on the forthcoming DECC specification documents (See Table 6). However, some assumptions can be made based on the documents that have already been released.

The smart meter functionality, relevant to smart grid applications, described in SMETS-2 can be split into the following categories; Power and Energy use, Voltage Monitoring and Demand Response. An overview of the SMETS-2 smart meter functions can be found in Table 7. A list of related data that

[4] "Intimate" refers to communication hubs housed within the electricity smart meters.

SMETS-2 smart meters will record (energy use, demand response and voltage) is shown in Appendix 1. There is no mention of any capability to record current or frequency in SMETS-2.

Category	Description of Electricity Smart Metering Capability
Power and Energy Use	Able to record energy import/export (kWh) on each of the 731 previous days. Able to record half hourly data (kWh) for: i. 13 months of Consumption; ii. 3 months of Active Energy Exported; iii. 3 months of Reactive Energy Imported; and iv. 3 months of Reactive Energy Exported. Able to record maximum energy use measured over a half hour period (since last reset). Able to compare active power to configurable thresholds ('Low-Medium', 'Medium-High' and 'Load-limit'). Able to record status of energy use as 'Low', 'Medium' or 'High' respectively.
Voltage Monitoring	Able to compare measured voltage to 6 configurable thresholds (3 high, 3 low); RMS over/under voltage detection, 'Extreme' over/under voltage detection and voltage sag/swell detection. Done across 4 configurable time frames RMS period, 'Extreme' period, sag and swell periods). Able to record events and send alerts when the voltage rises above high thresholds or falls below low thresholds for the related timeframe. Able to record supply interruptions. Sends supply restoration notification if interruption is over 3 minutes.
Demand response	Time of use pricing; Able to store 48 half-hourly prices (beginning at 00 or 30 minutes past the hour). Able to calculate an 'instantaneous cost' based on active power and tariff. Able to read status of and send commands to up to 5 HAN connected auxiliary load control switches. Able to store set of up to 200 'time-of-use switching' rules (in a 'calendar') for load switching (with a randomised offset); for changes in state across half-hours, days and dates. Able to request, ad-hoc, following receipt of a command, that one or more HAN connected auxiliary load control switches[5] change state. Able to, on receipt of a command, disable or enable the supply. Capable of supply disablement if power rises above 'Load-limit' threshold.

[5] Not all smart meters will include auxiliary load control switch(es)

Table 7 – An overview of electricity smart meter capabilities, applicable to smart grid applications, based on SMETS-2 [6].

4.1 The Home Area Network

Under the proposals, customer devices[6] will connect to the smart meter via the Communication Hub and Home Area Network (HAN), see Figure 5. There are two types of device, called Type 1 and Type 2. Type 1 devices are able to perform a range of 'Interface Commands' to set data (e.g. tariffs, thresholds), to perform commands (e.g. auxiliary load switch control) and to read data. Type 2 devices will provide "consumer access to the information stored" in the meter. Electricity smart meters shall be able to establish communication links (called CAD pairing) with at least seven Type 1 devices and at least four Type 2 devices. Both Type 1 and type 2 devices will receive alerts from the meter. A list of possible alerts from a SMETS-2 electricity smart meter is shown in Table 8. The extent and functionality of the Communication Hubs and the HAN will be addressed in the CHTS and GBCS, see Table 6.

HAN communication will be based on the Zigbee Smart Energy Profile and DLMS/COSEM[7] protocols [30]. Radio frequency communication will take place at 2.4Ghz (~70% households) and 868MHz (~25% households) – the remaining ~5% of households will use an as yet unconfirmed method instead, possibly power line carrier (these household include apartment blocks and houses with thick walls) [28].

The ongoing development of the Zigbee Smart Energy Profile could cause delays to the overall programme [28], In April 2014 DECC stated that locally-initiated CAD pairing will not be present at "Initial Live Operation" [30]. However, remotely-initiated CAD pairing (where the consumer provides information to any authorised third party to pair their devices remotely) is still included. It is therefore unclear whether customers will be able to send commands (e.g. those shown in Table 9) to their smart meter.

[6] Referred to as Consumer Access Devices (CADs) in the DECC documents
[7] Device Language Message Specification / Companion Specification for Energy Metering

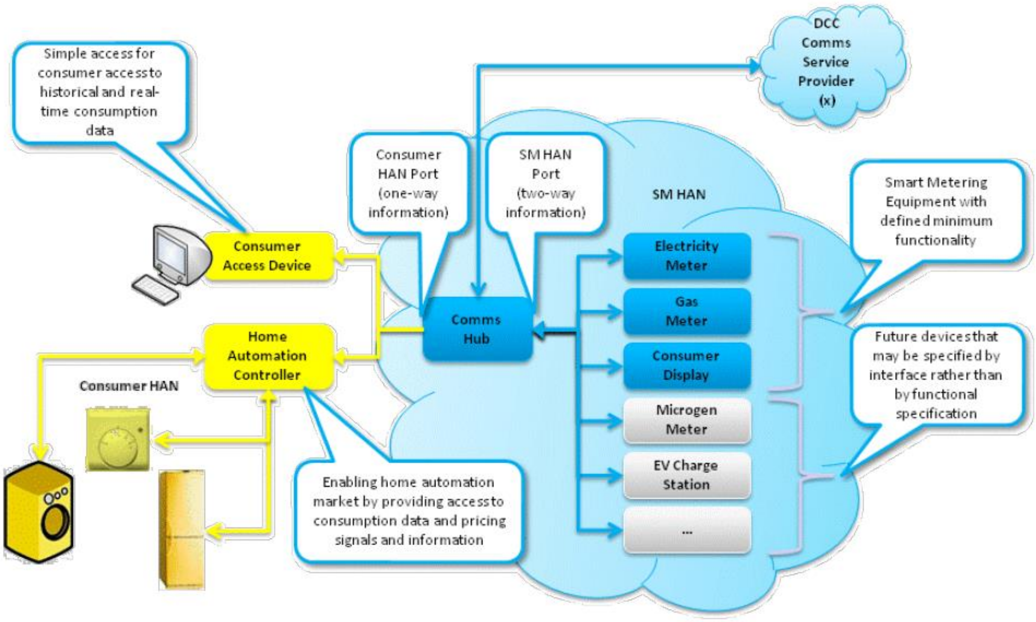

Figure 5 - Overview of possible connectivity in consumer premises, taken from [23]

Category	Message description
Physical security	Physical Tampering (Notification of supply tampering, or physical tampering with meter.)
Data security and validation	Failure to authenticate sender of command
	Failure to verify that it is intended recipient of command
	Command sender not authorised
	Confirm receipt and execution status of command
	Command invalid
	Supply state change (disabled or enabled) notification
	Supply armed notification
	Certificate Signing Requests (with public key)
	Personal data access notification
Billing/Credit	Emergency credit notification
	Low credit notification
	Low credit supply disablement notification
	Suspension of low credit supply disablement
	Credit notification
	Billing data notification (TOU Registers and Active Import/Export Registers)
Voltage Alarms	Average RMS Over Voltage Alarm
	Average RMS Under Voltage Alarm
	Extreme RMS Over Voltage Alarm
	Extreme RMS Under Voltage Alarm
	Voltage Sag Detection Alarm
	Voltage Swell Detection Alarm
Supply restoration reporting	Supply Restoration notification – after outage
	Supply Restoration notification, with time details (sent if outage > 3 minutes)
Load monitoring	Load above a configurable threshold for a configurable time
Demand Response	Confirmation (or notification of failure) of operation of HAN connected auxiliary load switch
	Confirm change to HAN connected auxiliary load switch calendar
Data read	Data read – response to a read command, includes the requested data (e.g. see memory designations in Appendix 1)

Table 8 - Messages sendable from SMETS-2 electricity smart meters via the HAN

SMETS-2 electricity smart meters accept demand response commands. These include commands to; change Time of Use Tariffs, change load switching rules, directly switch auxiliary load switches or directly disconnect /re-connect the supply, see Table 9. The meters can also instruct auxiliary load switches to operate – this is done following an ad-hoc request from a Type 1 device or following a preset rule within the load switching calendar, see Table 10. Use of the supply disconnector facility is intended for payment protection purposes. However, its use for demand response purposes is not ruled out.

Command	Description
Arm Supply	A command to Arm the Supply (A precursor to enablement).
Enable Supply	A Command to Enable the Supply.
Disable Supply	A command to Disable the Supply.
Set Tariff	A command to set TOU prices.
Write Configuration Data	A command to write configuration data (e.g. maximum power thresholds, voltage thresholds and load switching calendar rules)
Set HAN Connected Auxiliary Load Control Switch [n] State	A command to issue a "Request ad-hoc HAN Connected Auxiliary Load Control Switch [n] State Change" command to the HAN connected Auxiliary Load Control Switch [n].

Table 9 - SMETS-2 Demand Response commands receivable by Smart Meters via the HAN

Command	Description
Request ad-hoc HAN Connected Auxiliary Load Control Switch [n] State Change	Requests that a HAN connected Auxiliary Load Control Switch [n] either opens or closes its switch for a time period specified within the command. The command shall include a time period. When this time period has elapsed, the smart shall send a command to revert to the load switching rules in the load switching calendar.
Request calendar-based HAN Connected Auxiliary Load Control Switch [n] State Change	Requests that a HAN connected Auxiliary Load Control Switch [n] either closes its switch for a time period specified within the command, or opens its switch. Based on the rules stored in the load switching calendar.

Table 10 - SMETS-2 Demand Response commands sendable by Smart Meters via the HAN

5 Research Areas

5.1 Models of distribution networks

To test the effectiveness of using smart meter data for distribution network control, researchers need example distribution networks and software models to represent communication and control elements. Presently, a researcher might use an existing template test model or real network data provided by a network operator. Existing templates include:

- The UK Generic Distribution Network (UK-GDS) [31]
- Example Network from Department of Trade and Industry (DTI) report - “The Impact of Small Scale Embedded Generation on the Operating Parameters of Distribution Networks” [32]
- IEEE test feeders [33]
- Other examples from research papers [34][35].

The UK-GDS templates are accepted as a reasonable representation of the various types of distribution networks in the UK. However, they do not extend to the LV (400V) system. Whilst one example of an urban LV network can be found in a DTI report from 2003[32], a set of UK-GDS templates for the LV system, covering the most common configurations, would be of benefit to the research community.

Smart-grid control strategies are not tested using a common model or common scenarios. This means that it is difficult to easily compare the effectiveness of different proposed control schemes. For instance, any control scheme based on smart metering data will depend upon assumed communication latencies and message failure rates. Therefore, for comparison of proposed smart grid schemes, a “UK generic active distribution network” model, including both communication and power system models, would be useful. Inclusion of smart metering data access and demand response functions in any such model would be important.

5.2 Modelling timeframes

Traditionally, modelling of electricity networks and the associated equipment operate on a range of different timescales. These are illustrated along with application areas by Milano [36], see Figure 6. Studies of new equipment and control systems takes place across a relatively small portion of the x-axis. As interaction between control systems becomes more complex, there may be a need to examine control schemes with many objectives across wider timescales. Finding ways to combine traditionally separate modelling domains (e.g. steady state and transient) will become important [37].

5.3 Demand modelling for Demand Response

An important input in the modelling of any electricity network is the value (e.g. P, Q or **Z**) assigned to demand and generation. Reliable demand models are required to assess effectiveness of smart metering based (or other) demand response schemes and their impact on the electricity network. In MV and LV parts of the network, modelling of individual household loads may be considered. Literature and computer programs exist for the modelling of domestic loads including models down to appliance level [38] [39]. However, these models do not typically include data on loads that are expected to affect the operation of the LV system, such as Heat pumps and Electric Vehicles.

If, as is expected, a high proportion of domestic heating becomes electrified then a method of modelling the expected load is required. Any such model would have to include the influence of the thermal capacity of a particular dwelling and the external temperature. Producing a simplified model, in a way that does not produce an overly burdensome computational load, remains a challenge.

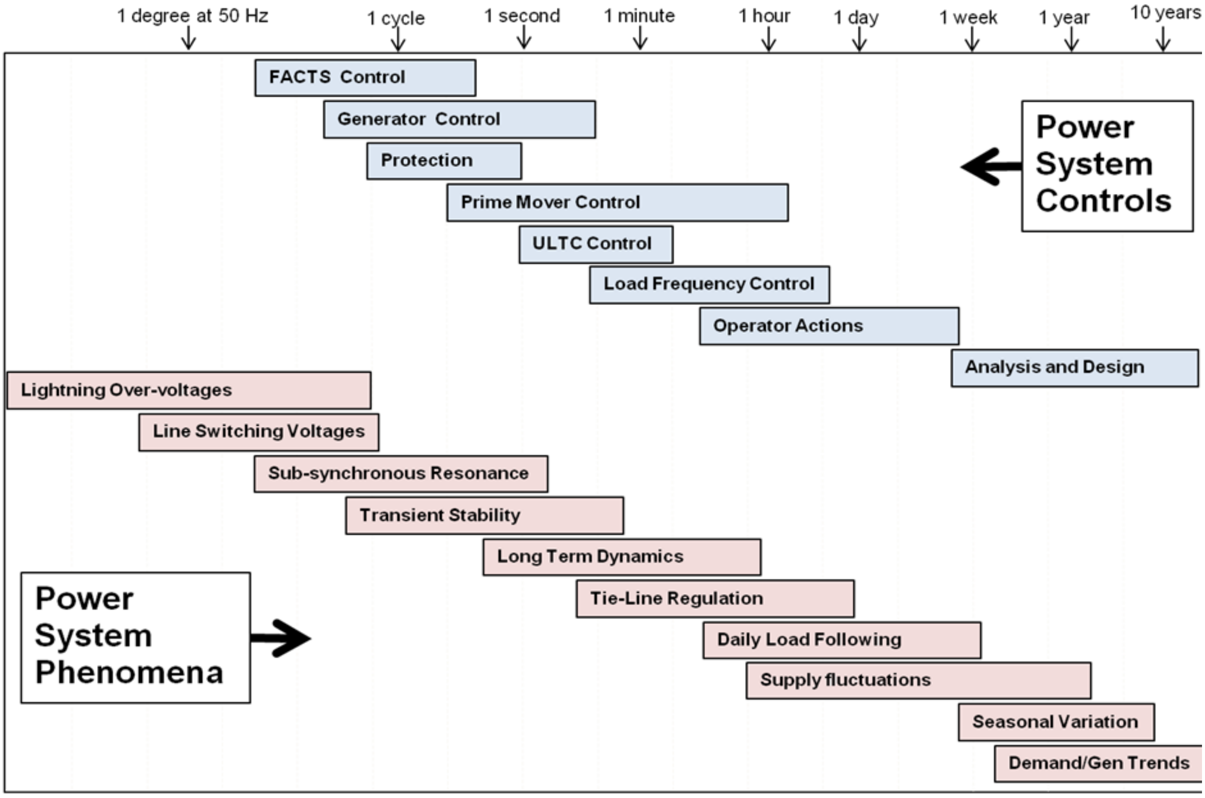

Figure 6 - Timescales of power system dynamics. Taken from [36]

5.4 Efficacy of Demand Response

Research on demand response in the non-domestic sector is required**.** Much of the discussion and research (on uses of smart metering for network operation and planning) focuses on domestic loads. This is understandable as the GB smart metering roll-out is targeted at domestic and small non-domestic customers. However, whilst domestic customers make up 92% of metered connections, they make up only 35 % of the UK annual electrical energy demand [40]. Also, more electricity demand models are available to the research community for the domestic sector than for the non-domestic sector.

Element Energy Ltd and De Montfort University found that non-domestic buildings (not including heavy industry) contribute around 15GW (30%) to the evening peak on a winter weekday [41]. They conclude that winter peak demands in Britain could be reduced by 14.5GW through demand side response from non-domestic buildings (not including heavy industry) but highlight concern over the flexibility of the lighting load in practice. They offer a reduced estimate of 0.6-2GW with no contribution from lighting. Research is required to ascertain how each of the load types (identified in Figure 7) can respond.

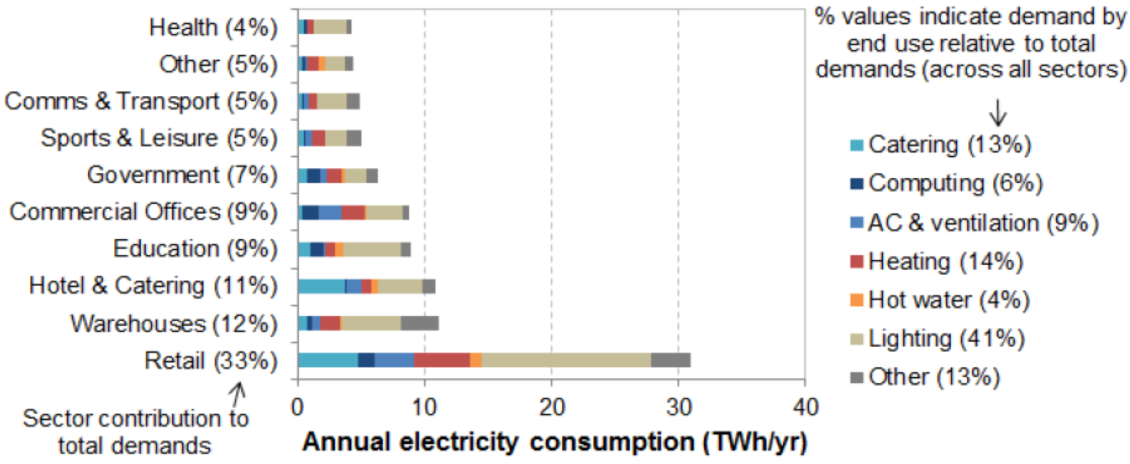

Figure 7 - Non-domestic energy use in Britain by sector and end use (excludes industry). Taken from [41]

There is potential for a significant growth in domestic demand and generation. This is due to three predicted trends; growth in the number of electric vehicles, growth in electrical heating (heat pumps) and growth in the amount of installed solar PV. Investigation of how these new demands should be automated and manipulated based on network and generation constraints is an active research area.

Communication between smart meters and external actors can be described as 'regulated' or 'unregulated'. Regulated communication will be overseen by a new licensed body, the Data Communications Company (DCC) and will be sent via the Wide Area Network (WAN). In contrast, unregulated communication will be sent via the customer's own communications connections and must therefore be separately agreed (and data forwarded) by the customer. Which data will be sent via regulated communications, and which must be sent by unregulated communication, is yet to be confirmed. All communication will be routed via communications hubs provided for each premises. These coordinate the 'regulated' external communications (over the WAN) and the communication with the meters, appliances and displays within the premises (over the HAN), see Figure 8.

It is anticipated that the UK smart meters will be able to report P and Q data over the HAN every ten seconds to In Home Displays(IHDs) [6]. This is of a higher granularity and lower latency than the regulated data streams. If agreements can be reached with individual customers, the high granularity data could be made available to third parties, such as network operators, via the customer's own internet connection.

Demand response aggregators might choose to use unregulated communication to monitor demand response availability and verify its use. However, there is concern that a growing reliance on internet based communication for provision of balancing and reserve could risk system stability as the exact nature and reliability of such communication may be unknown. There is presently little research in this area.

As the proportion of renewable generation increases, demand response incentives may be increasingly important to absorb excess energy from inflexible generators. Traditional fossil generators are being displaced by wind and solar generators, as the marginal cost of wind and solar is low. High output from these sources, coupled with low demand, means that traditional generation sources (e.g. nuclear or coal) may have difficulty in selling their output. In Germany, this has resulted in negative wholesale prices at times [42]. The potential influence of smart metering based Time of Use tariff demand response on this problem is not known.

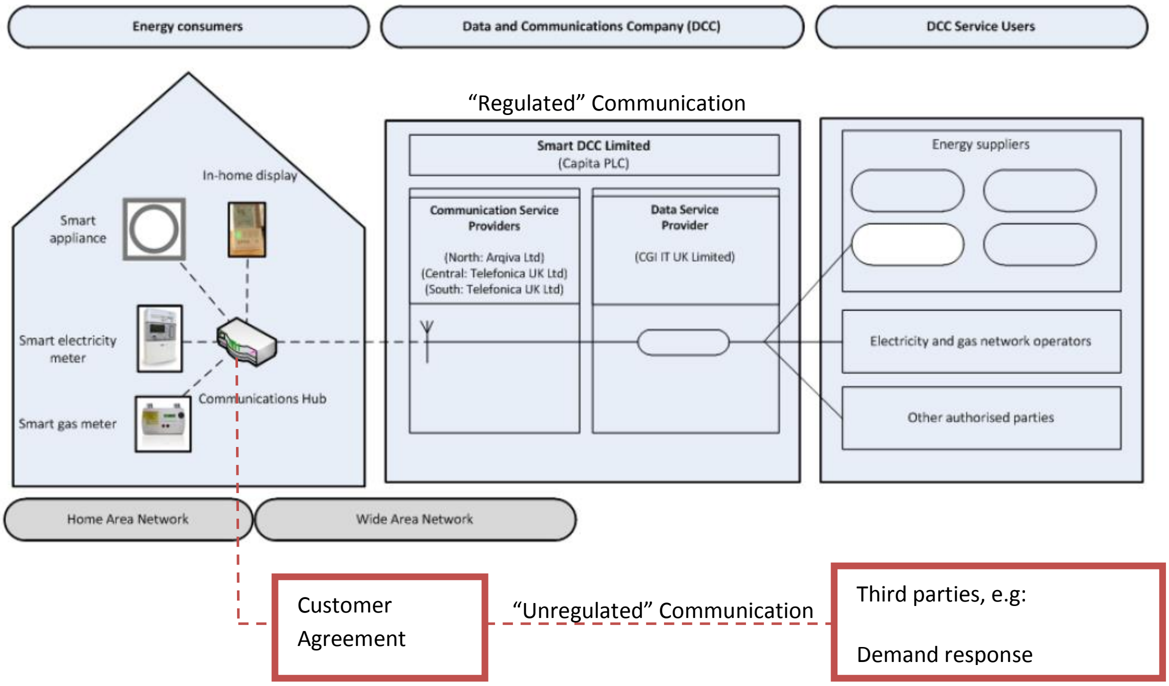

Figure 8 - Smart metering system diagram. After [43]

At present, Feed-in-tariffs, the reward for customers with generators up to 5MW, have no time of use component. It is conceivable that the smart metering system could be used to support delivery of time varying incentives for such generators. These may help to reduce costs (e.g. easing local capacity constraints). Research is required into the effectiveness of using ToU, or other, tariffs with DG. Sustainability First began to explore these issues in their paper on commercial arrangements for demand side participation[44].

5.5 Control of distribution power flows and voltages

To achieve a significant increase in asset utilisation and connection of renewable generation to the distribution network, new techniques for manipulation of power flows (and therefore voltages) can be applied [45]. Candidate technologies and techniques include; Soft Normally Open Points (SNOPs), distribution transformer tap changers, voltage regulators, reactive compensation, system reconfiguration schemes, generator/demand response and energy storage.

Power electronic converters at distributed generators (e.g. PV inverters), link points on open rings (e.g. SNOPs) and at demand (e.g. Electric Vehicle chargers) are able to influence power flows. At present, cost and physical size constraints represent a limiting factor in the implementation of SNOPs. This physical limitation is also true of distribution transformer tap-changers.

Best practice for the co-ordination of localised control actions, such as tap changers on 11kV:0.415kV transformers or power electronic converters, has not yet been established. Two extremes of control philosophy are centralised and de-centralised. At the decentralised extreme, each controller decides what action to take based on the information available to it. At the centralised extreme, a single central controller dictates the action of all local controllers.

Between the centralised and decentralised extremes, the controllers have some degree of autonomy and some degree of central co-ordination; there are numerous fields of study related to this type of system. Some of these are described in Table 11. Each of the concepts shown include elements, commonly referred to as agents, which are able to decide whether or not to perform actions based on available information. The application of multi-agent systems to power system has been explored [46][47]. However, how smart metering data can be made use of in such systems remains an open question.

Field of study	Description
Autonomic Systems	"Computing systems that can manage themselves given high-level objectives from administrators"[48]
Autonomic Power System	"... provides flexible and adaptable control through fully distributed intelligence and control"[49]
Complex systems	"...systems with many parts that interact to produce global behaviour that cannot easily be explained in terms of interactions between the individual constituent elements."[50]
Distributed Artificial Intelligence	"The subfield of AI concerned with co-ordinated, concurrent action and problem solving"[51] "... concerned with the study and construction of semi-autonomous automated systems that interact with each other and their environments."[52]
Distributed System	"A software system whose constituent parts run on different computers connected by a network"[53]
Game Theory	"... studies interactions among self interested agents"[54]
Multi-agent Systems	"Multi-agent systems are those systems that include multiple autonomous entities with either diverging information or diverging interests, or both" [55]
Semantic Computing	"Semantic Computing addresses technologies which facilitate activities that allow users to create, manipulate or retrieve computational content based on semantics ("meaning", "intention"), where "content" may be anything such as video, audio, text, software, hardware, network, environment, process, etc."[56]
Smart Grid	A next-generation electrical power system that is typified by the increased use of communications and information technology in the generation, delivery and consumption of electrical energy [57].

Table 11 - Fields of study applicable to control philosophies for power networks

5.6 Transmission system operation

The NETSO (National Electricity Transmission System Operator), presently National Grid Plc, has no published formal[8] plans to make use of smart metering data or demand response capability. However, there are areas where use could be made. Osborne et al, in their paper "The Impact of New Technology on Network Resilience" [37], highlight areas where challenges are anticipated. These include lower synchronous inertia, declining Q/P ratios at grid supply points, lower night-time minimum total demand (increased variation of voltage levels) and increased range of fault levels.

As the proportion of electrical energy generated by wind turbines and other renewables Increases, the number of frequency excursions tends to increase [58][59] and the expected maximum rate of change of frequency also increases [60]. Traditionally, frequency excursions on electrical power systems are controlled using governors on steam driven generators [61]. However, if the proportion of steam driven plant is reduced, there is a need to provide frequency response by other means. Simulations undertaken by National Grid illustrate the changing low frequency response requirements with wind penetration and demand level, see Figure 9.

At present, the NETSO ensures that the system remains stable by defining Balancing Services (including provision for adequate frequency response) and allowing generators or relatively large non-domestic demand to offer to provide them. A barrier for demand side participation in Balancing Services, such as low frequency response, is the lack of access to the mechanism by which the NETSO accepts offers and bids for changes in large generation or demand (to ensure the system remains stable). It would be difficult for the NETSO to make individual agreements with smaller customers for provision of such services. Whether the smart metering system could facilitate access to Balancing Services for smaller customers, via aggregators and appliance manufacturers, remains an open question.

There are two main ways in which smart metering could facilitate demand side participation in balancing services; by co-ordinating demand response (via tariffs or direct control) and through verification of response (as the NETSO must have evidence that demand response was provided). Some investigation in this area has begun [62], [63].

National Grid has proposed a new Balancing Service, called Demand Side Balancing Reserve [64]. This is to apply on winter weekdays from 4pm to 8pm. It is proposed that the reserve be despatched via a web application or smart phone application and verified using half hourly metering. In their initial proposals, in June 2013, National Grid mentioned the use of smart metering to allow participation from the demand side [65]. However, this has since been removed; the latest proposals state that the participation will be from non-domestic customers with half-hourly metering and from "small" embedded generation or energy storage [66].

ENTSO-E (the European Network of Transmission System Operators) is developing a package of legally binding codes, including the Network Code on Demand Connection (NCDC[9]) [67]. It includes (potentially mandatory) requirements for Frequency Response and "Active Power Control" to be provided by temperature controlled loads such as fridges, freezers and heat pumps [68]. This might remove any requirement for smart meters to provide frequency response verification. However research is required to ascertain the confidence with which the NETSO can predict the frequency response provided by a given population of temperature respondent devices. Some work in this area is ongoing [69].

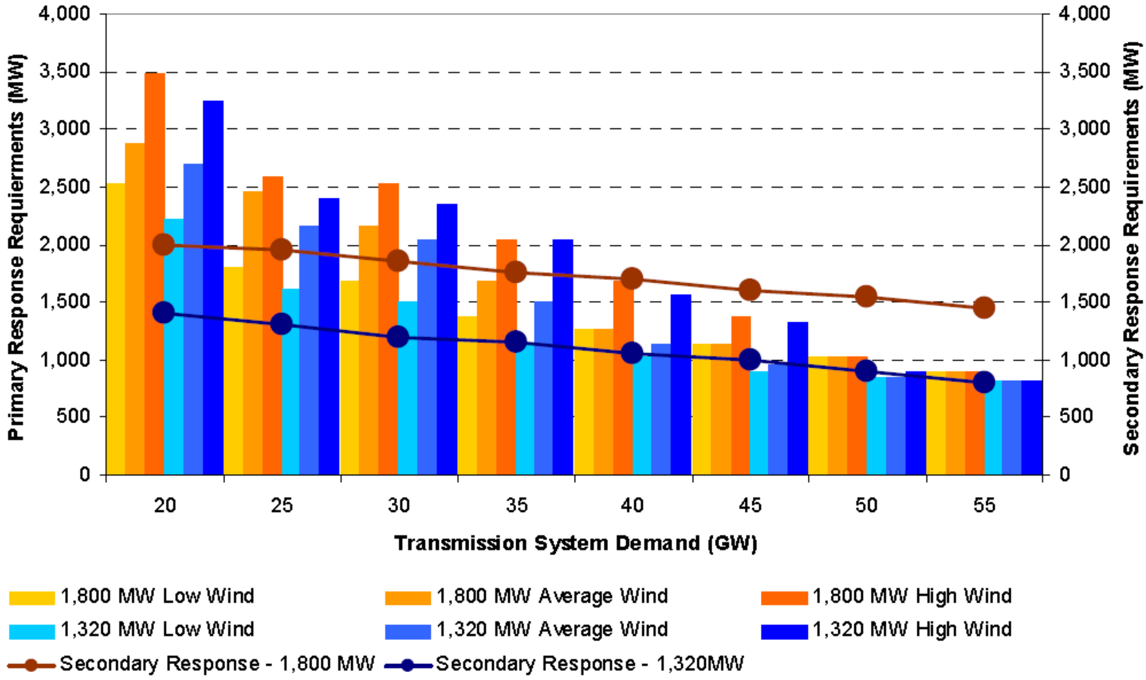

Figure 9 – A summary of the GB transmission system low frequency response requirement, for varying demand and wind generation, derived from simulations by the National Grid Frequency Response Technical Sub-group. Taken from [70].

An area where demand response may find use is to react to bottleneck constraints on the transmission network. National Grid already has a Balancing Service for this, named Transmission Constraint Agreement. It involves National Grid taking actions in the market to increase and decrease the amount of electricity at different locations on the network. It is done to mitigate congestion in areas of the network [71]. If small customers can be exposed to this, based on their location, there is perhaps possibility that smart metering based demand response will help ease such congestion constraints. Investigation is required to assess the feasibility of this idea.

Another possible influence on demand response is increased interconnection with the continental and Irish systems. Response to this is less geographically restricted than response to congestion constraints. Investigation into how much additional variation in power flows can be expected from multiple interconnectors must first be done.

An idea of allowing the GB network to, on occasion, decouple into islanded fragments may become more feasible if the location and quantity of all power demand and generation can be known. Whether this concept can be used to maintain or improve security of supply is not clear.

5.7 Visualisation and decision support

Osborne et al [37] raise concern that engineers “will get lost trawling through data” as a result of increased volumes of data being collected. They go on to say that a range of visualisation and decision support tools are required to prevent engineers becoming overwhelmed. What information

[8] Smart meters are mentioned in a superseded “informal” consultation on a proposed new Balancing Service [65] ,Demand Side Balancing Reserve, discussed later in this section.

[9] Note the ENTSO-E and other literature commonly refer to this as the Demand Connection Code or DCC. This is not used here to avoid confusion with the Data Communications Company.

must be communicated, and when it should be delivered, are fundamental questions. The closely related question of how the information should be presented is also important.

Establishing a way to demonstrate the fault-free operation of new visualisation and decision support tools is crucial and must be done before network operators can gain confidence in new tools. Where decision support tools morph into automated decision making, unforeseen control interactions may occur, owing to the inherent complexity of the power system - this is something to be guarded against. Developing a test system that captures this complexity, without incurring costly and time consuming computation penalties, remains a challenge.

5.8 State estimation of distribution networks

Knowing the state (voltages and voltage angles at all points, and power flows between busbars) of a distribution network enables the DNO to manage constraints (e.g. equipment thermal ratings, insulation limits). The state can be estimated using the previous day's half hourly usage data, supplemented by relatively few real-time measurements within the distribution network [72] . If data can be obtained from some smart meters at a reduced latency and increased granularity, possibly using the unregulated (see Figure 8) communication, then DNOs may be able to improve state estimation accuracy. The investigation of distribution system state estimation algorithms is an active research area.

Furthermore, smart meters will be equipped with over/under voltage alarms [6]. This data could be used by DNOs as basis to understand local constraints and to perform control actions (or influence tariffs).

5.9 Standards and guidelines

Relaxation of voltage standards is a way to allow increased penetration of distributed generation. Voltage rise caused by generators is a commonly cited limit of the connection of generators [73][74]. If the range of allowable voltages at a customer's premises could be widened, the generation hosting capacity may be increased. The extent to which limits could be adjusted is not known. DNOs are not presently aware of the exact voltage levels at the customer's points of connection. It is therefore possible that some customers presently see voltages that are outside limits. Smart meters could help find any such locations and provide data for the re-assessment of present voltage limits.

5.10 Disaggregation

In order to prioritise behaviour change (or appliance replacement), a customer must be able to identify which appliances are relatively costly and which are relatively inexpensive – Non-intrusive load monitoring, or load disaggregation, of smart meter demand profiles is a way to achieve this. Load disaggregation is the process of taking a total household demand profile and breaking it down into a number of separate load profiles representing different appliances. There is active research in this area [75][76].

5.11 Protection systems

Existing protection systems, and the underlying assumptions on which they are based, are a barrier to the de-carbonisation of the electricity network. The network is assumed to have mainly centralised generation and a high-inertia, this has a number of advantages:

- A substantial fault current is generated under short circuit or earth faults. This is easily detected by protection systems for isolation of part of the network.
- The system is robust – it is relatively unaffected by transient faults
- The system can withstand fluctuations in demand or generation
- Fault currents flow centrally outwards from transmission to distribution, allowing protective devices to discriminate so that the number of disrupted customers is minimised.

The disadvantages to this centralised, high-inertia, model include:

- The connection of low inertia sources (wind, solar) is limited
- Distributed generators must be switched off to protect islanding (the fragmentation of the network into smaller, less stable, lower inertia networks) – this can be detrimental to the demand generation balance and therefore lower stability in that way.

There is little research on the application of smart metering in the area of protection systems. Traditional distribution network protection systems rely on the estimation of highest and lowest short circuit or earth fault currents at different points on the network. Overcurrent protection relays are set to operate, and discriminate with each other, based on these fault levels. Increasing levels of distributed generation may change the assumptions about fault levels and cause overcurrent protection systems to malfunction. Using smart meters to dynamically estimate fault levels (based on monitored generation/demand) as a basis to update protection relay settings is perhaps possible – whether this can improve system security or improve DG hosting capacity is unproven.

Two other applications, outage management and fault location were identified in the precursor to this paper [1]. The research challenges and directions associated with developing a UK smart grid blueprint that integrates smart control and protection functions are detailed in another HubNet position paper [77].

5.12 Data Privacy

There may be a challenge to network planners and operators in maintaining data privacy whilst making use of smart meter data. How smart meter data should be made suitably anonymous whilst maintaining sufficient location information to be of use for given applications (e.g. in a control scheme) has yet to be defined. In some cases, such as outage management, household locations and supply statuses are required to maintain service. In other applications (e.g. System Operator analysis of aggregated profiles) location information can be removed from the data. A compromise between quality of service and privacy is likely. The boundary between acceptable use of customer data and unacceptable use is for society to define. There are research challenges both in finding out the limits of acceptable use and in finding out how data can be suitably anonymised for different applications. Some work in this area exists[78]–[81].

5.13 Smart Metering Alternatives

An assumption that is made in consideration of uses for smart metering in distribution networks is that DNOs have little information about what is going on in their 11kV and LV systems. Therefore, if DNOs decide to install separate measuring equipment within their LV networks, the impact of smart metering may be diminished. The LCNF has funded the installation of voltage monitoring on the network in Western Power Distribution's (WPD) licence area as part of their LV Templates project [82]. How much reduction in WPD's need for smart metering data will be achieved using this approach is unclear. The LV templates project's "close down" report [83] suggested that DNO's would have difficulty in the setting up of voltage monitoring within consumer premises.

5.14 Governance

As the GB power system develops, new interactions between the main actors develop (see Figures 1 and 2). Conflicting objectives mean that new regulation and governance approaches will be required. For instance, conflict could arise where different parties want to use demand response tariffs to move demand in opposite directions (e.g. wind generators wishing to encourage demand during high wind and DNOs wishing to limit it due to local constraints). The significance of this problem is not known. Whilst a Low Carbon London (LCL) LCNF project is looking at the issue [84], it is not the primary focus of the project and it is not exploring the underlying regulatory problems that arise. Another example of a new interaction is the interface between the DNOs and end users for demand response.

There is a question of whether the present regulatory structure of the GB system is adequate and of how, if at all, it should be changed. As the power system develops, more information must be transferred between the DNOs and the NETSO (e.g. for NETSO monitoring of embedded generation or DNO anticipation of demand response). Notably, the IET's Power Network Joint Vision (PNJV) position statement [85] recommended that a System Architect role be created. The statement highlighted that, "Since privatisation in 1990, no single party has had the responsibility to ensure overall systems integration." These regulatory issues are likely to be addressed by the steering groups listed below. Finally, the EPSRC funded Autonomic Power System Project plans to design an autonomic power system for 2050 [86]. It may well inform the future direction of the GB power system.

Electricity North West's Capacity to Customers LCNF project is increasing network capacity by removing redundancy [87]. This raises the question of whether customers are prepared to accept a lower security of supply in exchange for a lower cost. Smart metering will allow for customers' continuity of supply to be monitored – therefore opening up potential for negotiation over security of supply versus infrastructure upgrade. It is probable that regulatory changes, not to mention a change in society's expectation of the power system, would be required for this to happen.

Steering groups have been formed to discuss and influence the technical and regulatory development of the GB electricity network. These groups include:

- DECC and OFGEM Smart Grid Forum
- Energy Networks Strategy Group (ENSG) – co-coordinated by DECC and OFGEM
- IET Power Networks Joint Vision (PNJV)

- OFGEM Smarter Markets Consultations – concerns change of suppler processes and Demand Response regulation.

6 Conclusions

The DECC smart metering specification and governance code drafts, relevant to development and operation of the GB power system, were listed in this paper and the related functionality was discussed. Whilst uncertainties remain, the overview given in this paper should give researchers, network operators, and other companies wishing to use smart metering data for network purposes a basis on which to make reasonable assumptions about the proposed GB smart metering system's operation.

Details on how smart metering will operate both within the home and as a whole system have not yet been finalised. This is reflected by the specifications still under development at the time of writing (June 2014) including; the final version of SMETS2v2[10], CHTS[11], ICHTS[12], SEC[13], DUGIS[14] and DCoCo[15]. Also, some of the responsibility for this detail lies with the suppliers (responsible for the specification of SMETS compliant meters) and the DCC[16] (responsible for provision data and communication in accordance with the Smart Energy Code). The open questions include the following (with the relevant pending specification documents in brackets):

- How will the smart meters work within the home? (SMETS2v2, CHTS, ICHTS)
- How will the network operators, suppliers and third parties be able to access smart meter data? (SEC, DUGIS and DCoCo)
- Which parties will have access to what data? (SEC, DUGIS and DCoCo)

The promising application areas identified in this paper and its precursor, Smart Metering for the UK [1], include; outage management, control scheme support, visualisation and decision support, state estimation, load disaggregation, protection systems, microgrids and islanding, phase identification, demand response (for energy use reduction, Balancing Services, wholesale market) and demand response verification. Related open research questions include:

- What is the efficacy of domestic and non-domestic demand response?
- How much automation should be adopted?
- Can use of smart metering data help improve power network hosting capacity for heat pumps, energy storage, electric vehicles and distributed generation?
- Can smart meters be used to identify phase connections and network configuration?
- How will consumer privacy be protected?
- What control philosophies should be adopted?
- How can engineers be prevented from "getting lost trawling though data"?

[10] SMETS2v2 - Version 2 of the second Smart Metering Equipment Technical Specification
[11] CHTS - Communication Hub Technical Specification
[12] ICHTS - Intimate Communication Hub Technical Specification
[13] SEC - Smart Energy Code
[14] DUGIS - DCC User Gateway Interface Specification
[15] DCoCo - DCC Code of Connection
[16] DCC – Data Communications Company

- What useful information can be taken from (both individual and aggregated) smart metering data?
- What should smart meter data visualisation tools look like?

Two valuable contributions of smart metering to electricity network operations could be input data for control schemes and visualisation/decision support. However, for researchers to validate new control ideas, models of the electricity network must improve – to take into account communication and data storage constraints. Also, as concern grows around the risks of unforeseen complex control actions, the domain areas of existing models must also grow. For instance, models spanning multiple timeframes, voltage levels and energy vectors may be required.

The open questions surrounding the proposed GB smart metering system's demand response capability are important. System operators will require strong evidence before firmly relying on demand response. Therefore, modelling must also encompass demand including, where necessary, human interaction with the network and new demand such as heat pumps and electric vehicles.

A scheme for sharing and validation of all types of software models across academia and industry could help avoid duplication of work, help network operators, manufacturers and other interested parties review and, where appropriate influence the direction of research. Well known code sharing websites do exist [88][89] – whether the power systems research community should make more use of these, or similar, tools is an open question. A central source of validated models (in proprietary software) would also be useful for researchers.

The analysis in this paper leads to some whole-system questions related to regulation and governance of the system. The most significant of these are listed below:

- Are customers prepared to accept a lower security of supply in exchange for a lower cost and, if so, how should society's expectation of the power system change?
- Is the present regulatory structure of the GB system adequate and how, if at all, should it be changed?
- Which parties should have control of demand response and how should it be regulated?
- How can whole system models be improved to better inform engineers in both operation and planning?
- Should system fault protection philosophies be changed to allow increased distributed generation?
- What role should customers play in the future GB power system?

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8 Appendix I - SMETS-2 smart meter recorded data relating to energy use, demand response and voltage

Tables based on the Department of Energy and Climate Change's Smart Metering Equipment Technical Specifications Version 2 (SMETS-2).

8.1 SMETS-2 smart meter recorded data relating to energy use

Register/Memory Designation	Description of Contents
Active Import Register	Cumulative Active Energy Imported
Active Power Import	The measured active power imported.
Active Export Register	Cumulative Active Energy Exported
Cumulative and Historical Value Store	Consumption (kWh) and cost: a. on the Day up to the Local Time; b. on each of the eight Days prior to such Day; c. in the Week in which the calculation is performed; d. in each of the five Weeks prior to such Week; e. in the month in which the calculation is performed; and f. in the thirteen months prior to such month.
Daily Consumption Log	Consumption (kWh) on each of the 731 Days prior to such Day arranged as a circular buffer.
Profile Data Log	UTC date and time-stamped half hourly data (the amount of energy Imported or Exported in a half hour period) arranged as a circular buffer Capable of storing: i. 13 months of Consumption; ii. 3 months of Active Energy Exported; iii. 3 months of Reactive Energy Imported; and iv. 3 months of Reactive Energy Exported.
Maximum Demand Active Energy Import Value	The largest date and time stamped value of Consumption recorded in any 30 minute period (commencing at the start of minutes 00 and 30 in each hour) since the value was last reset.
Maximum Demand (Configurable Time) Active Energy Import Value	The largest date and time-stamped value of Consumption recorded in any 30 minute period (commencing at the start of minutes 00 and 30 in each hour) within a configurable time period.
Maximum Demand Active Energy Export Value	The largest date and time-stamped value of the Active Energy Export recorded in any 30 minute period (commencing at the start of minutes 00 and 30 in each hour) since the log was last reset, together with the UTC date and time when the log was last reset
Reactive Export Register	Cumulative Reactive Energy Exported.
Reactive Import Register	Cumulative Reactive Energy Imported.
Daily Read Log	A log for storing fourteen UTC date and time stamped entries of the *Tariff TOU Register Matrix*, the *Tariff TOU Block Register Matrix*, the *Active Import Register* and the *Active Export Register* - a circular buffer.
Power Threshold Status	An indication of the Active Power level, being low, medium or high.
Cost of Instantaneous Active Power Import	The indicative cost in Currency Units of maintaining the Active Power Import for an hour at the Price(s) currently active.
Load Limit Counter	The number of times the *Active Power Import* has exceeded a configurable threshold for a configurable time period

Table 12 - SMETS-2 memory designations for energy use information

8.2 SMETS-2 smart meter recorded data relating to demand response

Register/Memory Designation	Description of Contents
Tariff TOU Register Matrix	A 1 x 48 matrix for storing Tariff Registers for Time-of-use Pricing
Tariff TOU Block Register Matrix	A 4 x 8 matrix for storing Tariff Registers for Time-of-use with Block Pricing
Tariff Block Counter Matrix	A 4 x 8 matrix for storing Block Counters for Block Pricing.
Tariff Threshold Matrix	A 3 x 8 matrix capable of holding thresholds in kWh for controlling Block Tariffs.
Tariff TOU Price Matrix	A 1 x 48 matrix containing prices for Time-of-use Pricing.
Tariff Block Price Matrix	A 4 x 8 matrix containing prices for Block Pricing.
Tariff Type	The Tariff type in operation, being Time-of-use or Time-of-use with Block.
Tariff Switching Table	A set of switching rules for allocating half-hourly Consumption to a Tariff Register for Time-of-use Pricing and Time-of-use with Block Pricing. The rules stored within the table shall support 200 Time-of-use switching rules per annum. The rules shall support allocation based on: i. half-hour, half-hours and half-hour ranges; ii. day, days and day ranges; and iii. date, dates and date ranges.
Cost of Instantaneous Active Power Import	The indicative cost in Currency Units of maintaining the Active Power Import for an hour at the Price(s) currently active.
Auxiliary Load Control Switch [n] Calendar	Switches as open and closed. The rules stored within the calendar shall support 200 Time-of-use switching rules per annum. The rules shall support changes in state based on: i. half-hour, half-hours and half-hour ranges; ii. day, days and day ranges; and iii. date, dates and date ranges.
Auxiliary Load Control Switch [n] Description	For each Auxiliary Load Control Switch, a description of the type of controlled load connected and the switch type.
Disablement Threshold	The threshold in Currency Units for controlling when to Disable the Supply
Load Limit Period	The length of time in seconds which the *Active Power Import* needs to continuously exceed the *Load Limit Power Threshold* before a load limiting event is deemed to have occurred.
Load Limit Power Threshold	The Active Power threshold in kW
Load Limit Restoration Period	The length of time in minutes after the Supply has been Armed following a Load Limiting Event before the Supply is Enabled
Load Limit Supply State	A setting to control the state of the Supply in the case of a load limiting occurring, being Disabled or unchanged.
Randomised Offset	The product of the *Randomised Offset Limit (*A value in seconds in the range 0 to 1799) and the *Randomised Offset Number* (a randomly generated number between 0 and 1) rounded to the nearest second. This value is used to delay the Tariff Switching Table times and the Auxiliary Load Control Switch switching times.
HAN Connected Auxiliary Load Control Switch [n] State	The commanded state of Auxiliary Load Control Switch [n], (where n is between 1 and 5) being open or closed.

Table 13 - SMETS-2 memory designations for demand response information

8.3 SMETS-2 smart meter recorded data relating to voltage

Average RMS Over Voltage Threshold	The average RMS voltage above which an over voltage condition is reported.
Average RMS Under Voltage Threshold	The average RMS voltage below which an under voltage condition is reported.
Average RMS Voltage Measurement Period	The length of time in minutes over which the RMS voltage is averaged.
RMS Extreme Over Voltage Measurement Period	The duration in seconds used to measure an extreme over voltage condition.
RMS Extreme Over Voltage Threshold	The RMS voltage above which an extreme over voltage condition is reported.
RMS Extreme Under Voltage Threshold	The RMS voltage below which an extreme under voltage condition is reported. The threshold shall be configurable within the specified operating range of ESME.
RMS Voltage Sag Measurement Period	The duration in seconds used to measure a voltage sag condition.
RMS Voltage Swell Measurement Period	The duration in seconds used to measure a voltage swell condition.
RMS Voltage Sag Threshold	The RMS voltage below which a sag condition is reported.
RMS Voltage Swell Threshold	The RMS voltage above which a swell condition is reported.

Table 14 - SMETS-2 memory designations for voltage information