Visions of a Highly Distributed Energy Future

Over the coming years, the UK electricity system will see major changes in the electricity generating mix, with implications for system operation and reliability. Approximately 12 GW of nuclear plant is to be retired by 2025 and 11 GW of coal fired power stations expected to close to meet the Large Combustion Plant Directive. At the same time, a massive expansion in renewables, mainly offshore and onshore wind is expected in order to meet government 2020 renewable energy targets. With 35 GW of wind power anticipated for the GB electricity system and with just 10 GW of nuclear power plants connected, the operational flexibility of the system will become a critical question. Under such circumstances, control of centralised fossil plant will not be sufficient to ensure system reliability. Therefore distributed generators and the demand side must help support network operation. The decarbonising of our energy sector by 2030 will be difficult without a major contribution from responsive loads.

This is the vision of a highly distributed energy future, where the electricity system is supported by the coordinated control of millions of small scale loads and microgenerators. The role of the householder is critical – it implies active participation of householders in the operation of the electricity system. This could be either passive, where microgeneration and smart appliances in the home operate at times that is beneficial to the system as a whole, or by more active energy management where householders directly control when they use appliances or run heating in response to an outside signal.

Under either case, the house needs to receive information about the wider state of the electricity system in order to decide on a response. This information flow to the home is essential, and smart meters enabled with two-way communication are seen as the hub that enables the household response. The question is: what information needs to be communicated to the home, and what are the implications for the smart meter specification.

What is a smart meter?

The introduction of smart metering in the UK is widely seen as an important contributor to reducing CO_2 emissions from power generation and energy supply in line with stringent policy targets. According to the Government, *“smart meters will play an important role in our transition to a low carbon economy, and in helping meet some of the long term challenges that we face in ensuring affordable, secure and sustainable energy”*.

There are smart meters for electricity, but gas and water meters have also been developed. In general, smart metering assists in the temporal management of a resource through advanced tariffs, so electricity meters are by far the most developed as supply and demand are both variable and need to be matched instantaneously. However, the term ‘smart-meter’ has no universally agreed definition, and is used to cover a wide range of specifications. One that would be applicable just about anywhere comes from The Climate Group (2008) which defines smart meters as “*advanced meters that identify consumption in more detail than conventional meters and communicate via a network back to the utility for monitoring and billing purposes.”*

Broadly speaking, a smart meter is a meter that is capable of electronic communication which enables suppliers to read the meter remotely, known as automated meter reading (AMR). However, a fully smart (electric) meter could do a great deal more than that utilising two-way communication or automated meter management (AMM) This could include: remote disconnection and reconnection; managing changes in prices; tariffs (including shifts between credit and prepayment); time of day or real time pricing; measuring generated or exported electricity from microgeneration; contractual power changes and supplier switching remotely; providing detailed information on voltage and frequency to the network manager. There is also the potential for direct load control of appliances via the meter, and remote limitation of power drawn.

Broadly, the benefits of smart metering can be split into those that benefit the utility, customer (or both), and those benefits that accrue in the short term from AMM, and those that will be longer term arising from additional functionalities of smart metering. It is these longer term benefits that are of interest to this work, as it is primarily the additional functionalities that will be necessary for the adoption of a highly distributed energy future.

However, the current debates around smart metering are typically focussing on the details of automated meter reading and energy feedback to the consumer. The longer term capabilities are receiving less attention, yet with only one planned roll-out of smart meters it is imperative that the necessary functionalities are included in the specifications now. Failure to do so runs the risk of precluding a highly distributed energy future, and may necessitate more expensive grid management solutions.

Utility Benefits	Both benefit	Consumer benefits
Short term		
Lower metering costs and more frequent readings thanks to remote reading	Better customer service	Energy savings as a result of improved feedback thanks to real time information and more frequent and accurate billing
Variable pricing schemes	Remote disconnections/reconnections or changes in available power	
Limiting commercial losses due to easier detection of fraud/theft	Easy switch to pre-payment	
Longer term		
Reducing peak demand via demand response programmes reduces cost of purchasing wholesale electricity at peak time	Decrease in complaints via call centres	Simplification of payments for microgeneration
Better planning of network and generation/maintenance	Using communication infrastructure to remotely control distributed generation rewards consumer and lowers cost for utility	Additional payments for wider system benefits
Ability to sell other services (*e.g.* broadband)	Enabling adoption of electric vehicles, whilst minimising increases in peak demand	
	Time of use tariffs	

Smart metering Policy

There have been many domestic smart-metering initiatives implemented world-wide and a number of complete or near-complete rollouts of electrical smart meters in Italy, Ontario, and Sweden. A mandatory rollout in the Netherlands was started, but was halted because of a successful challenge on data privacy grounds. Customers are now taking new meters only on a voluntary basis. The UK is planning a complete roll out of smart meters for electricity by 2020.

The motivation for these schemes also varies – in Italy non-technical losses (theft) were a major consideration, others were introduced to allow demand side participation to reduce peak demand in networks where reserve capacity is small. The UK is unusual to date in including some form of customer display in its definition of a meter, with the aim of reducing CO_2 emissions by providing better customer information.

Policy is driven by a number of Directives at EU level, notably 2006/32/EC Energy Services Directive which recognised the importance of electronic metering in energy saving measures and 2009/72/EC (Electricity) Directive which requires implementation of intelligent metering systems that shall assist active participation of consumers by 2020. It requires member states to ensure the interoperability and to consider the use of appropriate standards. The EC standardisation mandate on “Smart Utility Meters” (M/441) in 2009 was given to the European Standard organisations CEN/CENELEC/ETSI to create a standard that enable interoperability of utility meters with open architecture by 2010 and additional functions by 2013.

The Government’s response to the smart metering consultation, published January 2010, states that the Government believe smart grids can “*be fostered effectively […], in particular by ensuring the requirements of network business are reflected appropriately in the minimum meter specification and the communications solution*”. The Energy Networks Association is currently working alongside Ofgem to develop meter specifications to support future smart grids. This workshop is seen as an academic contribution to this process.

Benefits of smart metering to the electricity system

Though main drivers of the smart meter initiatives in the UK are of interest to meter operators and energy suppliers, widespread deployment of Smart Meters will bring much greater visibility of the low voltage network, where presently there are very limited measurements to show the voltage and power flows. Better visibility of the low voltage network will allow: improved operation of the distribution network and better utilisation of distribution assets as well as aggregation of distributed generation so that its contribution to the operation of the power system can be traded and managed (Virtual Power Plant concept). These objectives are of interest to network operators and generators.

Real-time control facilities provided by smart meters will enable coordinated control of appliances and the information provided by the smart meters can be used for coordinated control of every single element of the power system (switches, on load tap changers, generators, power electronic controllers) to provide: ancillary services such as frequency response and reserve; peak shaving and shifting; voltage control; economic dispatch and unit commitment; distribution system optimisation and reconfiguration; and enhanced outage management.

In appliance control, the debate on which appliances can be controlled and how continues, and the details of what is socially acceptable and technically feasible are not yet agreed. Micro-generation will have a significant effect upon the local electricity distribution network in the future, but could be extremely beneficial if heating appliances (micro-CHP, heat pumps) used in conjunction with thermal stores (hot water tank, building envelope) can be scheduled according to network requirements. Similarly scheduling of charging/ discharging electric vehicles will be extremely important in future.

Network planning decisions could, in future, be based on data collected from smart meters and allow for the delay of building new power plants and transmission infrastructure, with subsequent cost savings. Furthermore, the data cold also be used to identify sections of the grid to be improved.

In accommodating intermittent renewables and load management, smart metering can potentially reduce additional investment of grid capacity requirement and may provide a management interface between the installed components with the aim of providing the most economic energy supply to the consumer.

The need for information

Information could be recorded and provided on a number of timescales. Currently consumption is recorded (or indeed estimated) on a quarterly basis but this timescale does not provide the electricity industry or consumers with an opportunity to “learn” anything about consumption habits. By recording more frequently, a more accurate picture could be developed. However this could result in an excessive amount of information so frequency of the recording of information must balance the conjugate principles of requiring information without having too much information that its value is negated.

With the expected control functions half hourly sampling would be ineffective and more accurate information would be required at the level of the transmission and distribution system. The polling time interval should be determined by the requirements from the smart grid functions as shown in the table below, and the capability of the ICT infrastructure. Suitable protocols should be identified (or improve existing ones) that facilitate data prioritization such that each type of data are delivered on time. Clearly the desired functionality will have major implications for the meter specification.

Data/Application	Maximum Delivery Time	Note
a. Line Sectionalizing	5 s	
b. Load control and load	10 s	Non-underfrequency
shedding		condition
c. Load shedding for	10 ms	Triggered by
underfrequency	10 ms	underfrequency relay
d. Fault identification,	10 s	reporting function
isolation and service		
Restoration		
e. Fault isolation	Several minutes	
service restoration		
f. Transfer switching	24 ms	
g. VAR dispatch	1 s	
h. Voltage dispatch	1 s	
i. SCADA–stand-alone	1 s	
or distributed		

A further consideration is the extent to which the smart meter is measuring data locally, which implies extra hardware. Clearly it is necessary to record energy flows, potentially on several different circuits, but frequency, voltage could also be measured by the smart meter and used to provide information back to the DNO, or used as signals to control the operation of smart appliances. Further data could also be collected which may prove useful to household energy management, such as internal and external temperatures.

Tariffs to support a Highly Distributed Energy Future

In order to support a highly distributed energy future, new electricity tariffs will need to be implemented and may be broad ranging in terms of appeal and purpose. Some companies such as EDF have already begun to implement a two-cost agreement with their consumers where energy is cheaper in the evenings and weekends and this is likely to form the basis of most tariffs in the coming years. Beyond this point, where variability of renewable supply overrides the traditional concept of times of peak demand, real time pricing will be necessary to provide information as to when loads and generation should be deployed.

Equally feasible is the deployment of a two-price tariff with a cheaper price for “controlled” loads that may be switched on or off by the network operator and a more expensive price for “uncontrolled” loads that may not be switched on or off by the network operator. An example of this would be a customer not being able to use their washing machine during peak time as its on the cheaper rate connection but being able to watch their television at any time due to it being on the more expensive rate. However, such a tariff would have monitoring implications in the home with separate electrical circuits and energy measurements for each.

Similar arrangements will be necessary to support feed-in tariffs where generation (and ideally export) must be recorded, and assigned to the appropriate tariff. It is also likely in future that electric vehicles will have their own tariff to compensate for the loss of tax revenue from decreased petrol sales.

The role of DNOs

Despite being regional natural monopolies, DNOs are regulated by Ofgem price controls. New price controls will be put in place in 2010 that will influence greatly what roles DNOs will have. The proposed price controls will focus firstly on reducing environmental impact, secondly on making it easier for customers to be more energy efficient and finally making sure DNOs adjust in time to the network changes anticipated in future years.

With regard to reducing environmental impact, DNOs must look towards minimising electricity losses across the distribution network. DNOs also need to prepare for smart grids capable of accommodating all generation and storage options, such as microgeneration and electric vehicles. The full effects of implementing new technologies may not be observed for a number of years but DNOs will have to prepare for what the future holds.

The technical requirements for the effective use of Smart Metering for system operation differ from those already identified for improved meter management and energy demand reduction. Much higher data rates are likely to be desirable with the associated increased performance of communication systems and requirement to manage data.

This leads to the following questions:

- What system operation functions are to be facilitated through Smart Metering?
- Hence, what is the appropriate data rate and accuracy of SM data for operation (Distribution, Transmission and Generation)?
- What level of reliability is required?
- Has the role of Aggregators (Commercial and Technical VPP operators) and how they will access the smart meter data been considered?

Communications

There are many factors being taken into consideration regarding communications among all the smart meter manufacturers. The different options include the mobile phone network, radios, and power line communications or combinations thereof. The primary problem in power line communications is the lack of capacity at higher frequencies; however the use of radio communications could overcome this constraint, at the expense of signal quality.

Fixed wireless and wireless mesh networks are in existence at present and could be readily implemented. The mesh network has the benefit of being able to cope with a damaged branch and helps to ensure the reliability of the overall system. For the consideration of security and reliability, there are many problems such as various environments and signal privacy to be worked out in order to provide effective wireless communication. Within the home, devices could connect to the smart meter using established protocols such as Bluetooth, WiFi and General Packet Radio Service (GPRS).

Broadly the following conclusions can be reached about the communications requirements:

- Data granularity and quality: The expected readings are typically at every ½ hour which is needed for time of use tariffs, but would a communications centre be able to efficiently manage data from each individual household on a half-hourly basis? What if more frequent updates are required from the household (within a few minutes timescale e.g. outage and power restoration management, control of micro-generation)?
- Bandwidth: The bandwidth should be sufficiently large to support finer granularity of data or future uses to which the communications infrastructure might be put in order to support the grid.
- Technology: The technologies that are currently being deployed will be very different from those that will be available in 2020, but the meters that are going out now have no way of being able to upgrade the communications hardware (includes energy displays, websites, appliance monitoring and control).
- The meter should have communication interfaces for Wide Area Network (WAN) (to communicate outside the home) and Home Area Network (HAN).

- Communications solutions should be highly reliable, robust and secure (i.e. cannot be interfered with).
- They must be feasible for all places within the UK (i.e. even in remote areas). The communications equipment itself must be energy efficient.

The system operation requires accurate real-time measurements. Nowadays metering and communication hardware equipment should meet the accuracy requirements mandated by the standards. On the other hand, reading data from large amount of smart meters over a communication media will cause notable time delay. As the power system loads are dynamic, the time delays implicate errors of the measurements. Therefore heterogeneous communication networks used in smart grid applications should satisfy the time delay performance required for the applications.

Conclusions

Whilst smart meters are clearly essential components of a smart grid, their exact specification remains to be decided and is dependent of the functionalities desired. Within the home, the smart meter may be required to provide information to householders regarding price under time-of day and real time tariffs. Energy forecast information may also be required to enable households to respond appropriately. Alongside this, smart appliances will need to access the smart meter to optimally schedule their demand, according to a signal, which may be price, but could also be locally measured voltage or frequency. Direct load control, whereby suppliers can control loads directly is also possible, but remains of debateable acceptance to the majority of consumers.

The meter itself will need to record a wide range of information. With price varying by time of day, and potentially different prices for different loads, different types of microgeneration and export, a large number of energy measurements may need to be made and recorded. Additional measurements may prove useful, such as voltage and frequency, to provide information to the DNO to aid network management.

Timescale of information is a critical issue with a range of information requirements ranging from sub-second to conventional ½ hourly metering depending on the system functionality required. This has knock on implications for the communications network in terms of bandwidth and data handling requirements.