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Demand side management: Benefits and challenges[☆]

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ABSTRACT

In this paper, the major benefits and challenges of electricity demand side management (DSM) are discussed in the context of the UK electricity system. The relatively low utilisation of generation and networks (of about 50%) means that there is significant scope for DSM to contribute to increasing the efficiency of the system investment. The importance of the diversity of electricity load is discussed and the negative effects of DSM on load diversity illustrated. Ageing assets, the growth in renewable and other low-carbon generation technologies and advances in information and communication technologies are identified as major additional drivers that could lead to wider applications of DSM in the medium term. Potential benefits of DSM are discussed in the context of generation and of transmission and distribution networks. The provision of back-up capacity by generation may not be efficient as it will be needed relatively infrequently, and DSM may be better placed to support security. We also present an analysis of the value of DSM in balancing generation and demand in a future UK electricity system with significant variable renewable generation. We give a number of reasons for the relatively slow uptake of DSM, particularly in the residential, commercial and small business sectors. They include a lack of metering, information and communication infrastructure, lack of understanding of the benefits of DSM, problems with the competitiveness of DSM when compared with traditional approaches, an increase in the complexity of system operation and inappropriate market incentives.

1. Key features of the present power systems and the opportunities for demand side management (DSM)

The traditional electricity system has four main sectors: generation, bulk transmission, distribution and consumption. Key features of each of the sectors are briefly reviewed in the context of the discussion of the potential role of DSM to improve the efficiency of operation and investment in the system.

1.1. Generation capacity, plant utilisation and efficiency

In order to supply demand that varies daily and seasonally, and given that demand is largely uncontrollable and interruptions very costly, installed generation capacity must be able to meet maximum (peak) demand. In addition, there needs to be sufficient capacity available to deal with the uncertainty in generation availability and unpredicted demand increases. Historically, a capacity margin of around 20% was considered to be sufficient to provide adequate generation security. Given the average demand across the year, the average utilisation of the generation capacity is below 55%. This relatively low average plant utilisation opens up significant scope for DSM as shifting load from peak to off-peak periods would reduce the need for generation capacity and increase the utilisation of generating plant and hence increase the efficiency of generation investment.

There is a significant spread in utilisation among different generators. As a result, the lowest marginal cost plant would operate at about 85% load factor (e.g. combined cycle gas turbine, nuclear), while plant with the highest fuel cost (e.g. old open cycle gas turbine (OCGT)) would operate only a few hours per year. Clearly, by shifting load from peak to off-peak periods, generation fuel cost could be reduced and the utilisation of investment improved.

1.2. Utilisation of transmission and distribution networks

Historically, the design and structure of electricity transmission (and distribution) networks were driven by an overall design philosophy developed to support large-scale generation technologies. The network is able to continue to function after loss of a single circuit (or a double circuit on the same tower). After loss of a circuit due to a fault (e.g. lightning strike), the remaining circuits that take over the load of the faulty line must not become overloaded. This means that, under normal operation, during

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peak-load conditions, circuits in the interconnected transmission network are generally loaded below 50%.

Great Britain's transmission network is characterised by significant north–south power flows as there is more generation in the north and more load in the south. In order to keep the north-to-south flow within permissible limits, it may be occasionally required that northern generators with lower marginal costs are constrained 'off', and southern generators with higher marginal cost are constrained 'on', which increases the cost of operation. At present, these constraints-related costs are relatively small, but an increase in generation capacity in the north and/or reduction in generation capacity in the south would increase these costs. The cost of congestions is managed by appropriate investment in network capacity.

Distribution networks are operated as passive systems with real-time control problems being resolved in the planning stage. Integration of distributed generation in the operation of distribution networks and the need to develop active network management techniques are likely to facilitate the application of DSM to increase the utilisation of existing distribution network assets.

1.3. *Key features of demand*

Demand is largely uncontrollable and varies with time of day and season (there have been insufficient incentives for demand to become responsive). Minimum demand occurs in summer nights and is about 30% of the winter peak.

A key feature of demand is the diversity in usage of appliances. This is fully exploited in both electricity system design and operation. The capacity of an electricity system supplying several thousand households would be only about 10% of the total capacity that would be required if each individual household were to be self-sufficient (i.e. provide its own generation capacity). Distribution electricity networks are essential for achieving this significant benefit of load diversity. However, no material gains in the capacity of the electricity supply system would be made from increasing further the number of the households. This phenomenon is illustrated in Fig. 1, which shows how the demand coincidence factor changes with the number of households. The coincidence factor is the ratio between maximum coincident total demand of a group of households and the sum of maximum demands of individual consumers comprising the group. In other words, the coincidence factor represents the ratio of the capacity of a system required to supply a certain number of households and the total capacity of the supply system that would be required if each household were self-sufficient.

Therefore distribution networks have significant value as balancing demand and supply at the household level is clearly inefficient.

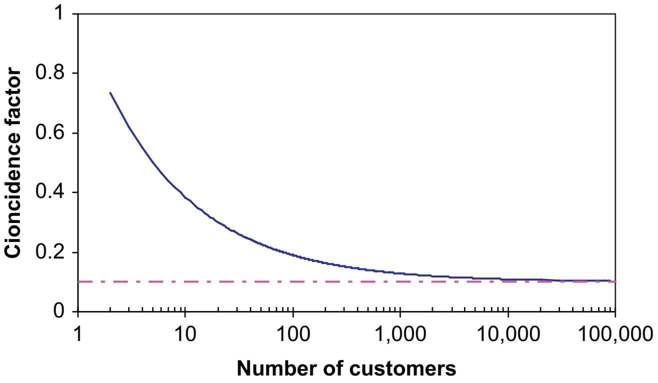

Fig. 1. Load coincidence factor as a function of the number of typical households.

1.4. *Load diversity and DSM*

It is important to stress that the application of DSM techniques tends to disturb the natural diversity of loads and create some undesirable effects.

Regular use of load control requires the ability of controlled devices (appliances) to reschedule operation (production) or the ability to continue operating during the interruptions by drawing on some form of storage. This storage can take the form of thermal, chemical or mechanical energy or intermediate products. DSM therefore redistributes the load but does not necessarily reduce the total energy consumed by the device (appliance). Load reduction periods will be followed or preceded by load recovery. The duration of the load recovery periods depend on the interrupted process and the nature of the storage.[1] In some cases, the amount of energy recovered may exceed the amount of load curtailed because of losses in the storage or energy conversion process.

In the case of directly controlling domestic appliances to change the shape of the system load, the process of load reduction and load recovery will need to be managed to achieve the desired effects. The key issue is the reduction of diversity of the appliances as a consequence of load control. For example, let us consider the behaviour of a population of 1000 refrigerators when used for demand management purposes. Assuming that each refrigerator, when operating, presents a load of 200 W and assuming a coincidence factor of 25%, the diversified load of 1000 refrigerators will be $1000 \times 0.200 \times 0.25 = 50$ kW, as only a quarter of the devices would operate (consume electricity) simultaneously. If all 1000 refrigerators are switched off, expected load reduction will be 50 kW. If these are, say, after 1 h then reconnected back to the supply, the load presented to the system is likely to be $1000 \times 0.200 = 200$ kW, because the temperature in all of the refrigerators will be above the set levels and thermostat control will result in all of the refrigerators operating in order to reduce the temperature.

So, this load control action would tend to reduce the diversity of the operation of controlled appliances and hence the total load of the group of the controlled devices would increase during the load recovery period. In order to counteract this load increase, some other appliances would generally be switched off, which clearly reduces the overall efficiency of load control.

One of the key technical challenges relevant to the competitiveness of DSM is to design approaches that would maximise the efficiency and utilisation of controlled loads.

2. Drivers for introducing DSM

Historically, the prospect of increasing the efficiency of system operation and the existing investment in the generation and transport of electricity has been the key driver for introducing DSM programmes.

Furthermore, commitment to market-based operation and deregulation of the electricity industry places consumers of electricity in the centre of the decision-making process regarding the operation and future development of the system. Clearly, development of DSM will support this general trend and provide choice to consumers regarding usage of electricity and preventing cross-subsidies among consumers. However, DSM has not yet been fully integrated into the operation of electricity markets.

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[1] Clearly, DSM and storage are inherently linked and should not be considered in isolation.

In addition, there are a number of other drivers that may accelerate the penetration of DSM, including the climate change challenge, development in information and communication technology (ICT) and the ageing assets of the electricity infrastructure.

The UK is committed to responding to the climate change challenge, and the energy sector, in particular the electricity industry, is expected to make a significant contribution to achieving this goal. In the last decade, the UK has supported the deployment of distributed generation of various technologies (particularly renewables and combined heat and power (CHP)) in order to reduce carbon emissions and to improve system efficiency. Given the interest in wind power especially, and the inherent variability of the output of this form of generation, there may be a useful role for DSM in the provision of system support services, such as different forms of operating reserve.

DSM should provide choice to consumers regarding the usage of electricity and prevent cross-subsidies among consumers. The ability to respond to fluctuations in electricity prices can also be an important risk management tool.

There have recently been some major advances made in ICT, which in principle could enable the deployment of various DSM options.

UK generation, transmission and distribution systems were considerably expanded in the late 1950s and early 1960s. These assets are now approaching the end of their useful life and it is expected that a significant proportion of these assets will need to be replaced in the next two decades. This opens up the question of the strategy for infrastructure replacement, in particular the design and investment in future electricity networks and the role that enabling technologies, such as DSM, will have in designing future electricity systems.

3. Benefits of DSM and future opportunities

In this section, a number of potential applications for DSM are discussed. Particular emphasis is placed on the value and competitiveness of DSM solutions.

3.1. Reducing the generation margin by DSM

As discussed above, the total capacity of installed generation in the system must be larger than the system maximum demand to ensure the security of supply in the face of uncertainty in available generation (i.e. generation breakdowns and interruptions to primary fuel sources) and variations in demand due to adverse weather. The former Central Electricity Generating Board, while planning the generation system, employed a generation security standard that required that demand disconnections were expected to occur in not more than nine in every 100 winters; this required about 24% plant margin to deal with such eventualities. The current electricity market arrangements do not contain a statutory or formal generation security standard that would define the required capacity margin for a particular mix of generation types.

Clearly, some of this long-term reserve can be provided by DSM. In order to examine the potential for DSM in this area, it is important to obtain the information about the frequency, duration and magnitudes of various potential deficits. Results of our preliminary investigations conducted, using a simplified UK generation model, are presented below. The magnitude of shortages and their respective frequency are found to vary over a wide range (Fig. 2).

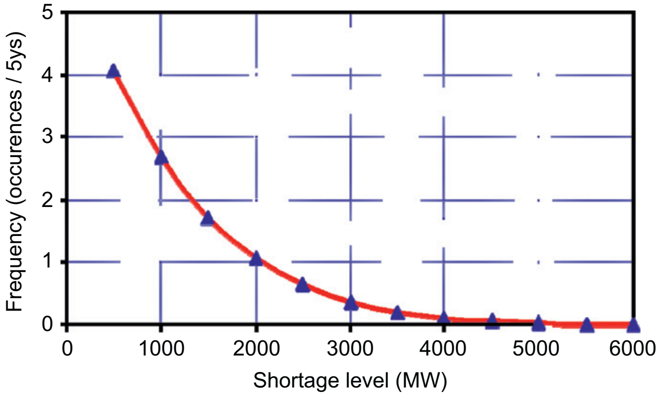

Fig. 2. Expected frequency and magnitude of shortages.

We can see a decreasing trend in the frequency of interruptions with the size of the deficit. For example, an interruption in which a 500 MW load would need to be curtailed would occur on average about four times in 5 years (i.e. almost every year, an interruption that requires a 500 MW curtailment), while we can expect a 2000 MW of load curtailment to occur on average once in 5 years. Furthermore, deficits larger than 5000 MW will be very rare.

This is clearly an important opportunity for DSM. Instead of dealing with such shortages by installing generation that would be used very infrequently, it may be possible to identify households that would be willing (for a fee) to forgo consumption relatively infrequently. The amount of load that we need is not massive in comparison to the size of the system. The value of DSM in this circumstance, determined by the cost of alternative provision of capacity which in this case is generation, would be about £250–£400/kW for a modern gas-fired-type plant. However, the value of DSM could increase considerably above the cost of generation due to difficulties and delays in the planning process associated with building new power stations.

This will be particularly relevant for future systems with a considerable contribution from renewable resources. Clearly, penetration of wind generation may displace a significant amount of energy produced by large conventional plant, but the ability of this technology to displace the capacity of conventional plant will be more limited. This is important as it will be necessary to retain a proportion of conventional plant to ensure that the security of supply is maintained. This will be an opportunity for DSM to provide an alternative form of reserve, as a conventional solution based on (stand by) generation is likely to be inefficient. The value of DSM will be bound by the cost of generation solutions, as indicated above.

3.2. Improving transmission grid investment and operation efficiency through DSM

Power system security is traditionally achieved through preventive measures: the system is prepared in advance to withstand credible outages (specified in accordance with the security standards), with no need for any immediate corrective action to be taken following the outage. This preventive security is achieved by dispatching generating units out of merit in order to make sure that no credible contingency would leave the system in an untenable situation. As a consequence, the system is operated 24 h a day, 365 days a year, less efficiently, in order to be able to cope with outages that occur infrequently. The advantage of such an operating philosophy is simplicity of operation, achieved at the expense of increased operating costs and low utilisation of generation and network capacity (generation utilisation is about 50%, while average utilisation of network capacity is even lower).

An alternative approach would be to operate the system at lower operating costs and with reduced network and generation capacity (therefore with higher utilisation), provided that overloads that occur after outages of circuits and generators can be effectively eliminated by carrying out appropriate corrective actions.

This could be achieved by curtailing some loads at appropriate locations. Clearly, this would allow generation to operate at a lower cost (as the congestion is reduced) and therefore transmission network investment can be varied while maintaining the existing levels of security. Recent advances in ICT could, in the near future, facilitate the change in operating philosophy from preventive to corrective.[2]

This assumes that some consumers would find it financially attractive to curtail or postpone their load to help correct an emergency situation. Our initial studies indicate that the value of controlling the transmission network by DSM in corrective mode could be significant, but it will strongly depend on the level of existing transmission capacity (system stress) and generation fuel cost differentials (Strbac et al., 1998). The value of DSM in this case would be limited by the operating and investment cost of the conventional preventive control approach (out-of-merit generation costs and transmission investment costs). The average cost of transmission network reinforcement in the UK is about £300/MW km, but this may increase due to difficulties with the planning process associated with transmission network reinforcements. In the context of the future British transmission network, given the dominant north–south power flows, installing significant amounts of renewable generation in the north of the country would increase the stress on the transmission network, and therefore the value of corrective control provided by DSM in the south of the country would increase.

3.3. Improving distribution network investment efficiency through DSM

Similarly, DSM could be used to manage network constraints at the distribution level. In general, DSM could bring a spectrum of potential benefits in terms of (i) deferring new network investment, (ii) increasing the amount of distributed generation that can be connected to the existing distribution network infrastructure, (iii) relieving voltage-constrained power transfer problems, (iv) relieving congestion in distribution substations, (v) simplifying outage management and enhancing the quality and security of supply to critical-load customers, and (vi) providing corresponding carbon reduction.

There is a particular issue emerging associated with increased loading of existing distribution substations in urban areas, driven by a significant increase in air-conditioning load. DSM could be used to manage this increase, and also for increasing the loading capabilities of the transformers. The problem is that space constraints within the substations would significantly limit the opportunities for replacing the existing overloaded transformers with new ones of larger capacity. In this case, there is an opportunity for the application of ice-cooling facilities aimed at increasing the short-term substation transformer rating by using the electricity to produce ice during the night that can then be used to cool the transformer during the daily peak conditions.

Similarly, DSM could be used to reduce peak flows through cables and transformers and enable an increased level of distributed generation to be connected to the existing distribution network.

The use of DSM for unlocking unused network capacity and the provision of system support services has not been widely considered. The value of the benefits of DSM technologies in releasing latent network capacity is not yet well understood and quantified, although our initial studies demonstrate that the potential may be significant (Jayantilal and Strbac, 1999). More work is required to examine the value and practicalities of DSM implementation in this context.

3.4. DSM in managing demand–supply balance in systems with intermittent renewables

To achieve a significant reduction in CO_2 emissions, renewables and other low-carbon energy sources will become major contributors to the UK electricity generation system. Wind power, both on- and offshore, is presently the principal commercially available and scaleable renewable energy technology. It will therefore deliver the majority of the required growth in renewable energy and continue to be the dominant renewable technology out to 2020. Although growth of these sources through to 2020 (and beyond) is envisaged, there are many concerns about the flexibility, variability, non-controllability of the sources and the impact this has on the ability to maintain the balance between demand and supply.

In order to deal with the increased uncertainty due to the penetration of wind generation, the system will need to apply increased amounts of reserve. This will generally be provided by a combination of synchronised and standing reserve. In order for synchronised conventional plant to provide reserve, it must run part-loaded. Thermal units, however, operate less efficiently when part-loaded, with an efficiency loss of 10–20%. Since some of the generators will run part-loaded to provide reserve (in case the output of wind generation reduces), some other units will need to be brought onto the system to supply energy that was originally allocated to the plant that is now running at reduced output. This usually means that plant with higher marginal costs will need to run, and this is another source of additional system cost. In addition to synchronised reserve, which is provided by part-loaded plant, the balancing task will also be supported by standing reserve, which is supplied by plant, such as OCGT, with higher fuel costs or through new techniques such as storage facilities or DSM.

The application of DSM, as a form of standing reserve could improve the system performance by increasing the amount of wind power that can be absorbed as fewer generating units are scheduled to operate, which is particularly relevant when high wind conditions coincide with low demand. In this context, DSM would allow more wind energy to be absorbed and would therefore reduce the fuel burned. The value of storage and DSM when providing standing reserves can be determined by the evaluation of the improvements in the performance of the system (fuel cost and CO_2 emissions).

Our study (Strbac and Black, 2004), which considered a system with 26 GW of wind capacity installed,[3] demonstrated that the key factor affecting the value of DSM was found to be the flexibility of conventional generation. We have therefore studied the behaviour of three generating systems of distinctly different flexibilities. Among the dynamic parameters of generating units considered, the capacity for plant to be turned on and off and the ability to run at low levels of output (minimum stable generation)

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[2] Evolution of feedback technology is already in progress in the form of phasor measurement units, which take time-stamped measurements of the key electrical quantities in magnitude and angle form and can sustain this at a high sampling rate.

[3] This amount of wind power would produce about 80 TWh per year, which would amount to 20% of the UK total energy demand.

Table 1
Characteristics of generation systems considered

Generation system	Parameters	Inflexible generation	Generation of moderate flexibility	Flexible generation
Low flexibility (LF)	MSG[a]	100%	77%	50%
	Capacity installed	8.4 GW	26 GW	>25.6 GW
Medium flexibility (MF)	MSG	100%	62%	50%
	Capacity installed	8.4 GW	26 GW	>25.6 GW
High flexibility (HF)	MSG	N/A	N/A	45%
	Capacity installed	0 GW	0 GW	>60 GW

[a] Minimum stable generation, expressed as a percentage of the maximum generator capacity.

were found to play a critical role.[4] The characteristics of the systems studied are presented in Table 1.

In Table 1, the base-load segment of the generation mix considered consists generally of inflexible plant that runs at full output and which can not be turned on and off frequently (such as nuclear). We have also incorporated a segment of the generation mix that includes plant that is moderately flexible, which can be turned on and off but with somewhat limited ability to run part-loaded (with relatively high minimum stable generation) and a segment of relatively flexible plant.

The significant amount of wind power in the system will cause an increase in fuel costs associated with balancing the system in real time. These costs are effectively fuel cost associated with holding and exercising the reserve necessary to manage fluctuations in demand and generation.

The additional value created by DSM is a result of reduced fuel consumption associated with balancing. This reduced fuel consumption leads to reduce fuel cost and reduced CO_2 emissions. The additional value of DSM when providing standing reserve for the balancing task is calculated by evaluating the difference in the performance of the system (fuel cost and CO_2 emissions) when balancing is managed via synchronised reserve only, against the performance of the system, with storage facilities used to provide standing reserve. The capitalised value of the annual reduction in fuel balancing cost, obtained from the application of DSM, is shown in Fig. 3.

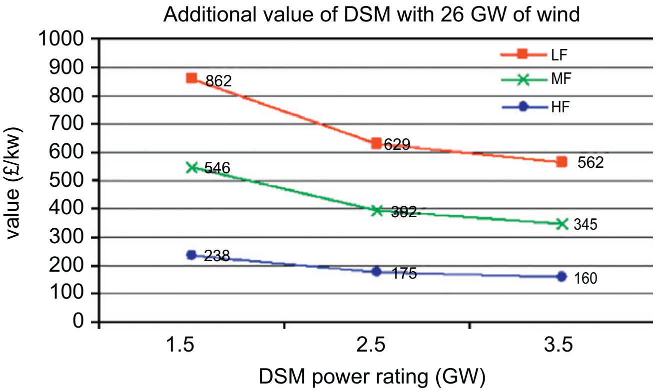

Fig. 3. Capitalised value of reduction of fuel cost with DSM.

Fig. 3 shows that it is only in cases of a system combining inflexible generation with significant amounts of unpredictable wind generation that DSM techniques might become competitive in providing reserve over the traditional solutions (i.e. spinning reserve).

As expected, the additional value that DSM created is greatest in systems with generators of low flexibility and decreases as the flexibility of generation mix improves.

However, when compared with traditional providers of standing reserve, such as OCGT plant, the competitive advantage of DSM is significantly reduced. Additional capitalised value of DSM over OCGT is shown to be less than £50/kW, which is unlikely to be sufficient to fund the implementation of DSM.

3.5. *The role of DSM in distributed power systems*

A radical shift from the present large-scale-based generation system to a system supplied by distributed medium and small CHP, together with various forms of renewable generation, would be driven by the prospect of significantly increasing the efficiency of the overall energy supply system. This would be primarily achieved by making use of rejected heat from medium and/or small thermal-based electricity generation, i.e. CHP, to supply space and water heating demand (i.e. CHP). It should be stressed that high energy and carbon prices could make such an integrated energy system financially attractive.

This 'dual-purpose'-based operation is very difficult to realise with units of very large sizes. Generating electricity from large plant is accompanied by the production of a very significant amount of waste heat that is difficult to make use of locally, and transporting it over long distances is inefficient.

Balancing electricity demand and supply in a distributed supply system dominated by different forms of renewable generation, including various forms of CHP, will be challenging. This is because the output of renewable generation (such as wind and photovoltaics) varies with weather conditions and it is not generally easy or desirable to modulate the output of renewables to follow a particular load shape. Similarly, the electrical output of domestic CHP schemes is expected to be driven by demand for heat.

The value of services associated with the balancing of demand and generation in this system is likely to be very significant, and demand is likely to be required to take a significantly more active role in matching electricity generation. Comprehensive, quantitative analyses of the economic and technical performance of alternative implementation options of such highly distributed power systems involving DSM would need to be carried out before firm recommendations could be made.

4. Brief review of DSM techniques

The concept of DSM is not new and key technologies for its implementation have been developed. Major techniques that have been put into practice are briefly reviewed below.

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[4] Ramp rates were not found to be particularly important, as long as the maximum rate of change of output of plant that provides synchronised reserve was above 5 MW/min, which is well within existing gas and coal technologies.

4.1. *Night-time heating with load switching*

Given that base-load plant operates with lower marginal costs, night-time electricity heating has been successfully applied in a number of countries. In the UK, Economy Seven tariffs were developed to support night-time storage heaters, which led to an increased domestic night-time load giving a more balanced use of the electricity generation and network across the day. This requires a two-register radio-teleswitched meter, with switching patterns for groups of meters provided to the BBC for onward transmission on Radio 4. As gas heating became popular, now less than 10% of customers have radio-teleswitched meters.

4.2. *Direct-load control*

Domestic direct-load control programmes apply to appliances that can be turned off or cycled for relatively short periods of time. The most common applications are domestic air-conditioners, water heaters and swimming pool pumps. Receiver systems are installed to enable communications from the utility and to institute controls. Communications are often by radio signal and power-line carrier. The utility cycles or shuts off an appliance for a limited number of hours for a limited number of occasions. Typically, users are free to operate the appliance when it is not under direct control.

Smarter control systems have memories built in to recognise how much the equipment has been running and are programmed to cycle at different frequencies so that all participants provide similar load reductions. Customers who take part in direct-control schemes receive compensation through reduced electricity bills.

A number of utilities, particularly in the USA, have experimented with direct load, while in the UK there has not been much interest in the application of load control. It is not clear if these experiments have been financially successful.

4.3. *Load limiters*

Load limiters limit the power that can be taken by individual consumers. The level at which the limit is set can be adjusted to reflect system conditions. This scheme offers some choice to users to decide themselves which appliances to use and what consumption to postpone.

4.4. *Commercial/industrial programmes*

Peak-load management programmes are available to commercial and industrial classes of customers. Particularly popular are load-interruptible programmes for the provision of reserve services and for enhancing system reliability. This interruptible load control is not exercised on a daily basis but is used to support the system following outages of generation or network facilities. Common participants included those with operations in refining, melting, manufacturing, mining and water treatment. There are also programmes for commercial customers where load is controlled by using the building control systems such as the heating ventilation and air-conditioning control, refrigeration controls and lighting controls.

4.5. *Frequency regulation*

System frequency is the direct measure of the balance between generation and system demand at any one instant and must be maintained continuously within narrow statutory limits of around 50 Hz. Given that Britain is an island, fluctuations in frequency are relatively significant. Following the loss of a large generator, frequency drops significantly and this signal is used to trigger load reductions that contribute (together with generators that operate part-loaded in frequency-sensitive mode), to frequency regulation. Large industrial consumers, such as aluminium smelters, take part in this activity.

More recently, there have been initiatives to investigate a technology that can be incorporated into electrical appliances to provide frequency regulation (see www.dynamicdemand.co.uk and www.responsiveload.com). Any electrical appliance that is time-flexible could be used and this could include industrial or commercial air-conditioners, water heaters and refrigeration.

4.6. *Time-of-use pricing*

Time-of-use (ToU) rates are designed to more closely reflect the production and investment cost structure, where rates are higher during peak periods and lower during off-peak periods. Key issues involve the design of ToU tariffs, i.e. the duration of individual periods and associated price levels. This method is widely practiced in a number of European countries, particularly for households with electric heating.

4.7. *Demand bidding*

Demand bidding programmes are available when the customer is willing to reduce or forgo their consumption of electricity at a certain predetermined price. One enabling technology is a programmable thermostat which controls the air-conditioning and heating systems. The thermostat can be programmed to adopt different settings depending on the electricity price levels. Furthermore, the thermostat can be programmed to change settings with seasons. The thermostats can also have a notification feature to alert residents of calls for action, as well as an override feature in case the customer chooses not to participate for the particular event. Various internet-based programs are also in development. Here, the customer obtains information on buy-back rates via internet connections and takes appropriate action to manage peak loads. A key issue in these programmes is how sophisticated or complex to make the price signals. There is also the issue of verification to confirm that some benefit was obtained when the thermostat and air-conditioning system responded.

4.8. *Smart metering and appliances*

It is widely accepted that some form of real-time pricing arrangements are required to efficiently allocate DSM resources and fully inform users about the value of electricity at each point in time and location.

Large sophisticated customers can already tie the electricity pricing into their energy management system. Greater price differentials between high- and low-cost periods could result in greater shifts of energy usage.[5] This needs to be accompanied by the application of intelligent appliances that would facilitate the implementation of DSM.

In order to facilitate such trading of energy among a very large number of smaller domestic participants, an electronic energy market system, supported by the internet, would need to be developed (an extension of power-exchange-type markets). Some

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[5] The price differentials are critical for the economics of DSM. For example, in systems with limited generation capacity, prices during peak demand should be significantly higher than during off-peak periods and this should stimulate DSM. However, if the prices are not sufficiently different, it will be difficult to justify investment in DSM programmes.

laboratory and pilot schemes that use multi-agent systems technology[6] have already been demonstrated.[7]

A number of other initiatives are associated with the introduction of smart appliances in residential homes. For example, as part of the effort to increase demand responsiveness, the California Energy Commission is currently constructing a new policy to require demand–response thermostats for new residential construction in California (see http://kingkong.me.berkeley.edu/DR/dreass/index.htm). Before demand–response systems can be effectively deployed on a wide scale in the residential sector, a number of technical challenges need to be resolved (infrastructure of communications, metering infrastructure, demand–response thermostats, etc.). This is likely to include some form of house energy management system that may rely on wireless technology that would automatically respond to price signals while taking into consideration the homeowner's preferences for cost versus comfort.

In this context, we welcome research and the pilot demonstration of smart metering, as indicated in the consultation undertaken by Ofgem (www.ofgem.gov.uk). There are two important issues: (i) to demonstrate and gain experience of the smart metering technology, but also (ii) to determine the functions required of smart metering. The latter remains unclear and greater clarity is required before national implementation of smart metering should be considered.

5. Challenges for DSM

The concept of DSM is not new and the key technologies for its implementation have already been developed. However, the implementation of DSM has been slow. A number of reasons can be identified that may be specific to the particular DSM scheme and system to which it is applied. These could include:

5.1. *Lack of ICT infrastructure*

Advanced metering, communications, control methods and information technologies are largely absent from electricity systems. In order to support the implementation of DSM in system operation, much more significant deployment of various sensors and advanced measurement and control devices will be required, accompanied by much more sophisticated energy metering and trading functions. This will lead to wide-ranging deployment of information and communication systems to facilitate the control of generators, loads and various network devices. Implementation of ICT for the control of electricity networks will lead to the development of an integrated energy and communications system architecture that is intended to integrate two systems in the power industry: the electrical delivery system and the information system (communication, networks and intelligence equipment) that controls it. There have been a number of initiatives (such as GridWise and IntelliGrid) in the USA and SmartGrids in the EU) intended to encourage the use of real-time information, integrating distributed intelligence using sensors, with demand–response programmes to maximise reliability and system efficiency while providing customers with new choices. Although the key ingredients of the technology exist, targeted trials are required to gain more experience with it in the context of DSM and network operation.

There needs to be a comprehensive analysis of the costs and benefits of installing such a sophisticated infrastructure. Commitment to its implementation would make the case for DSM significantly stronger.

5.2. *Lack of understanding of the benefits of DSM solutions*

As discussed above, the benefits and value of DSM are flexible in that it provides both system operation and system development. However, there has not been enough clarity regarding the business case for DSM, particularly due to a lack of methodologies for the quantification of costs and benefits. Significantly more work is required in this area. Broadly speaking, the magnitude of the value of DSM (i.e. the value of demand controllability) will be driven by the key operational features of the system. Particularly relevant in this context is the level of system stress, i.e. proximity of the system loading to its maximum capability and hence the need for reinforcement. In segments of the systems that need reinforcement, the value of DSM will be high, while in systems with significant spare capacity, the value of DSM will be generally low. In this context, the main barrier to DSM is network and generation capacity. So far, solutions based on network and generation capacity have been dominant and DSM schemes are exceptions rather than routine practice.

5.3. *DSM-based solutions are often not competitive when compared with traditional approaches*

Technical, economic and environmental performance of existing and future DSM schemes need to be comprehensively assessed. This is urgently required in order to objectively compare DSM and traditional solutions.

5.4. *DSM-based solutions tend to increase the complexity of the system operation when compared with traditional solutions*

Operating the power system with a corrective control approach will increase operational complexity. This is another barrier to the implementation of DSM. However, given that flexibility is now seen as an important tool to deal with the uncertainty in future developments, together with the continuous reduction in costs of DSM technologies, it is expected that in the near future DSM will become significantly more competitive. The development of targeted trial schemes will help to increase confidence in the use of DSM schemes for the provision of system security.

5.5. *Inappropriate market structure and lack of incentives*

The benefits of using enabling technologies such as DSM (or storage) often accrue to different participants. This presents a challenge for the development of a business case for these technologies as disaggregation and characterisation of their multi-stream value is a complex task. For example, action from DSM technologies that are part of a portfolio of generators can be used to balance output and provide energy arbitrage opportunities, which could accrue as benefits to the portfolio owner or to intermittent generators using this resource. In addition, this activity could contribute to more efficient use of existing network capacity, reducing (or delaying) the need for reinforcements and possibly contributing to other network activities such as securing the supply for local demand or relieving substation congestion. Therefore these benefits of storage and DSM participation can be associated with a number of industry sectors operating as individual businesses (e.g. generating companies, transmission and distribution network operators, etc.) that may all be willing to reward specific aspects of this activity. In the absence of the traditional vertically integrated utility that would be in a position

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[6] Agents are pieces of software that would, in this context, represent a device or household and could be designed to automatically negotiate production or consumption of energy.

[7] EU Project CRISP (Distributed Intelligence in Critical Infrastructures for Sustainable Power)—ENK5-CT-2002-00673.

to optimise the overall system value of such enabling technologies, there are multiple recipients of services provided by storage and DSM technologies. Establishing a business case for the application of these enabling technologies in this complex environment is not straightforward. Clearly, no individual recipient of the services (e.g. generating companies or distribution network operators) is interested in maximising the overall system benefits achieved by trading off the benefits between individual segments of the industry. In this context, an appropriate regulatory framework is essential to optimise the benefits of storage and DSM within a deregulated environment. Without this, the current regulatory arrangements may present a significant barrier to the introduction of these technologies.

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