BALANCING ELECTRICITY SUPPLY WITH DISTRIBUTION NETWORK CONSTRAINTS

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ABSTRACT

The need for electricity demand to adapt to distribution network constraints and intermittent supply from renewable generators is widely recognised. However addressing both these goals simultaneously with a single demand side management scheme is difficult within a deregulated industry framework. This paper describes a scalable method by which electricity suppliers can shape demand from domestic and SME consumers, particularly that arising from adoption of heat pumps and electric vehicles. A process is proposed by which Distribution Network Operators notify a maximum power profile for each connection to the supplier, who then uses it to shape demand from each consumer so that DNO limits are satisfied as a priority, and demand responds to supply availability as far as possible.

INTRODUCTION

Authors at a previous CIRED conference have shown that rising demand from electrical heating and vehicles will drive major distribution network reinforcement costs unless 24-hour demand profiles can be levelled [1]. This involves signalling to consumers to indicate when electricity use should be constrained and when distribution network capacity is available. However in an industry where transmission and distribution have been unbundled from supply of electricity, the relationship with each consumer is usually held by an electricity supplier in competition with other suppliers. Constraining demand on a distribution network segment therefore involves a complex interaction between a monopoly provider (the Distribution Network Operator[1] (DNO)), the competing electricity suppliers with customers on the network segment, and the consumers themselves. Balancing these interests and addressing other issues such as customer privacy and data confidentiality is a challenge for which no clear paradigmatic solution has emerged.

In Paper 0140 for session 4 we describe the technical details of a demand response signalling scheme that enables an electricity supplier to shape the 24-hour profile of electricity demand from their customers. In this paper for session 6 we summarise the signalling scheme and set out a regulatory framework and practical process by which this signalling scheme can allow constraints on demand to be applied to meet network capacity limits while recognising the interests of all the stakeholders.

BACKGROUND

Policy targets for decarbonisation of energy use have led to two emerging technological shifts with potentially major impacts on distribution networks. The first, which is particularly significant in the UK, is the replacement of fossil fuelled heating appliances with heat pumps. In [2] it is noted that the electricity demand of heat pumps is capable of being scheduled in time by making use of energy storage in hot water tanks and the thermal mass of the building. Secondly the adoption of electric vehicles (EVs) is progressively introducing a major new source of demand but also a potentially valuable electricity storage resource in the form of the vehicle batteries. The potential impact of these two developments is shown in Figure 1 which plots a simulation of default electricity demand over 24 hours for 1000 UK homes on a winter day. All the homes are heated using a heat pump with a coefficient of performance of 2.5 while 25% have one electric car with performance similar to the Nissan Leaf and average daily travel of 20km. It can be seen that the heat pumps and EVs increase demand in the early evening peak by a factor of at least 2.

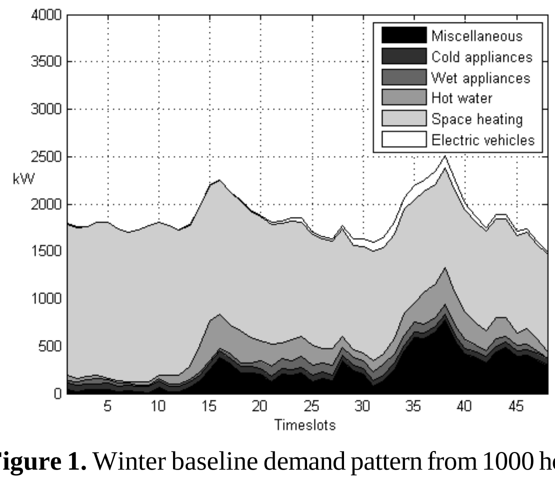

Figure 1. Winter baseline demand pattern from 1000 homes with heat pumps and electric vehicles**.**

1 In this paper Distribution Network Operator has exactly the same meaning as Distribution System Operator (DSO).

The need to flatten demand to avoid network reinforcement has led many authors e.g. [3],[4] to propose time-of use dependent tariffs in conjunction with charging or heating control units that seek to minimise the consumer's cost while satisfying consumer needs such as recharging a vehicle in time for its next use. The problem with this approach is that it tends to introduce new demand peaks either at the time a low cost tariff commences (where banded tariffs are employed) or at the minimum cost point (for continuously variable tariffs). This is demonstrated in [5] and [6]. Also, as reference [3] shows, the resulting feedback loop has the potential to cause oscillation in wholesale electricity prices. So simply communicating a variable price is not a satisfactory way to increase the efficiency with which distribution networks are utilised – it is essential that any scheme for discouraging or attracting demand reduces the peak to average ratio (PAR).

PROPOSED DEMAND RESPONSE SCHEME

The signal to electricity consumers

In the present work we have sought to address these issues with a concept for the interaction between electricity suppliers and consumers with the following features:

- The signal sent by electricity suppliers to consumers is a daily 48-value vector ***S*** that is not necessarily a tariff, but structured so that high values deter, and low values attract, electricity use in each half hour timeslot of the next 24 hours.
- A "smart" control unit in the home or office responds to this signal by scheduling demand within a time window that meets user's needs but in proportion to the attractiveness of the signal in each timeslot.
- Minimisation of cost with respect to wholesale prices is performed by the electricity supplier who sets the shape of ***S*** to meet their business needs and regulatory constraints.

To illustrate the operation of the smart controller, for a heat pump it introduces gaps in the running of the compressor that occur in the less attractive timeslots with a probability proportional to the unattractiveness of the timeslot. These gaps are controlled in their duration and make use of the thermal mass of the building so that the user's comfort is not impaired.

For vehicle charging, the charge in each timeslot within the user's acceptable time window is proportional to the attractiveness. The effect of this proportional behaviour when aggregated across a population of consumers is to ensure that the aggregate demand ***D*** has a linear relationship with the signal ***S*** governed by equations for each of the i=1:48 timeslots of the form:

$$D_i = B_i\,(1+ S_i\,k_i) + c_i \tag{1}$$

where ***B*** is the baseline demand in the absence of any signal as shown in Figure 1. The values of k_i and c_i can be determined from the response to ***S*** and provide a model which the supplier can use to predict demand and shape it within limits determined by the baseline demand and the constraints applied by consumers. Figure 2 illustrates the simulated outcome of levelling of demand across the same consumer population as Figure 1 using an optimisation function to determine ***S*** from (1) such that PAR is minimised, resulting in a PAR of 1.09 compared to 1.4 in Figure 1. For each individual household simulated, their requirements, such as availability of hot water when needed or completion of wet appliance cycles, have been respected in the levelling of demand.

Range of demand variation

In Figure 3 the range of possible values for ***D*** is shown given the same population and weather conditions as Figure 1. Clearly a supplier might wish to use this flexibility to match demand to their available supply, e.g. to make use of a short-term surge in wind generation, while a DNO will always prefer to have as low a PAR as possible. Note the early evening peak is reduced for all possible demand profiles, illustrating the inherent demand flattening properties of this scheme.

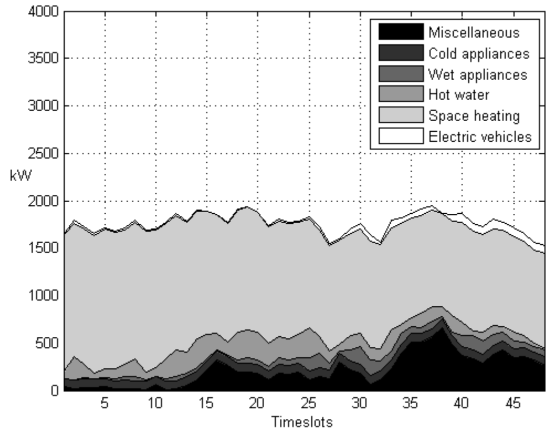

Figure 2. Response to a signal optimised for demand levelling

Figure 4 illustrates a scenario where a supplier wishes to attract demand into the overnight period when a surge in low cost wind generation is available and sends a signal ***S*** that within the limits shown in Figure 3, draws demand into the desired period. It would equally be possible to attract demand up to the upper limit of Figure 3 in the middle of the day to exploit embedded photovoltaic generation on a sunny day.

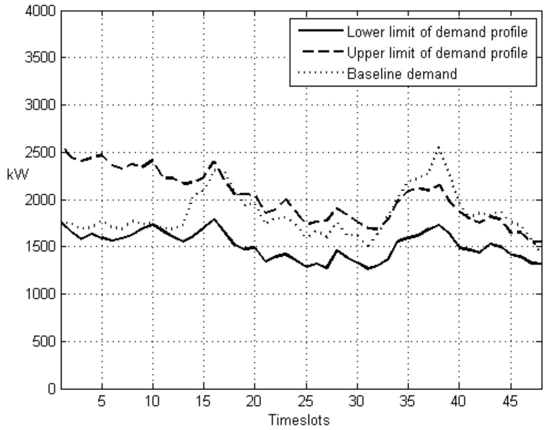

Figure 3. Upper and lower limits to demand response

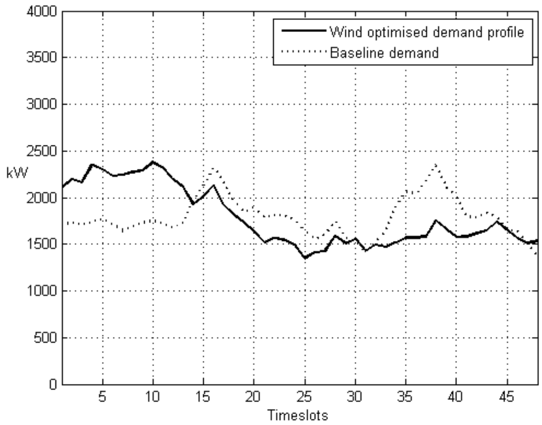

Figure 4. Demand optimised for overnight wind generation availability

It can be seen that this method is potentially valuable to both retail suppliers, for whom it can reduce the cost of wholesale generation and out-of-balance charges, and to DNOs for the ability to maximise the amount of energy carried by a fixed investment in network plant. In the next section we consider the regulatory and commercial issues and propose a process by which these interests can be reconciled. The process could be fully automated but depends on smart metering at half hour intervals.

DNO-SUPPLIER-CONSUMER RELATIONSHIP

The need for DNOs to have a more active role in the relationship between the consumer and the electricity industry has been highlighted in numerous recent studies e.g. [7], [8], particularly in the context of electric vehicle charging where the user will want to make use of charge points operated by the DNO. However the consensus appears to be that there should not be a direct commercial relationship between DNO and consumer or vehicle user, but that there will always be a mediating agent such as a conventional electricity retail supplier or an EV aggregator. This ensures that the entity facing the end user can always be subject to competition. It is therefore essential that the DNO can communicate its network constraints to the suppliers in a structured manner with a predictable outcome when they are incorporated with the supplier's requirements in a combined demand management signal.

Proposed process using maximum power profiles

Figure 5 illustrates the proposed process which exploits the flexibility of the demand management scheme described above. The DNO specifies a 48-value maximum power profile for each connection point (i.e. meter point) to the supplier holding the supply contract for that connection. This would be based on the capacity of the distribution plant, the type of consumer (i.e. domestic, commercial or industrial) and a cautious estimate of the available diversity for each timeslot bearing in mind that levelling of rising demand using the method described above will tend to reduce diversity between consumers. It will probably be appropriate to have different profiles for weekdays and weekends and seasons of the year.

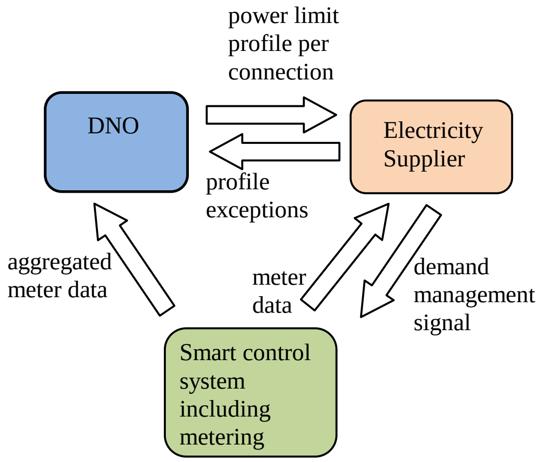

Figure 5. Proposed process for joint DNO/supplier demand management

DNO methodology

To calculate these profiled limits the DNO would use their own load measurements (e.g. taken at the LV transformer) combined with historic aggregated smart meter data giving profiles at half hour granularity for different network segments or nodes – it is assumed that confidentiality considerations would prevent the DNO having access to half hour data for an individual consumer. The methodology would involve the calculation of power flows on feeders, laterals and through each LV transformer of the network and voltages on all the nodes. In the case of highly meshed networks such as densely populated urban areas, methods such as Newton-Raphson and Gauss-Seidel could be employed, while the ladder technique could be used for radial or weakly-meshed rural networks. The methodology could also include the probabilistic LV planning approach proposed by Frame and Ault in [9]. It would have to be subject to industry wide agreement and regulation so that consumers could be confident that their maximum power profile had been determined equitably.

Supplier process

The supplier compares the maximum power profile provided by the DNO for each consumer with their historic metering data and assesses the risk of that consumer exceeding their profile, then allocates them to a group to receive an appropriate demand management signal depending on the risk. Consumers with little headroom would be sent a signal prioritised for flattening their demand as shown in Figure 2, whereas consumers connected with more network capacity could be given a signal which addressed suppliers' interests such as exploiting a wind generation surplus as shown in Figure 4.

The supplier would be obliged to operate a regulated audit process that would identify consumers who exceed their profile from metering data and give the DNO statistics for such occurrences. The stochastic nature of the response to the signal $\boldsymbol{S}$ means that a certain incidence of profile exceptions will inevitably occur. Where the level is excessive then the supplier would have to review their consumer categorisation and signalling policy. In a situation where the demand was being flattened as far as possible through induced response and the profile limits were still being exceeded then that would be evidence to justify network reinforcement or imposition of a physical tripping limit on consumption.

This process would ensure that the DNO's network capacity constraints are respected without any need for the DNO to interact directly with consumers on a routine basis or have access to their individual metering data (but DNOs would have metering totals for a feeder or geographical segment). The supplier would retain the primary relationship with the consumer and be responsible for the confidentiality and privacy issues in the processing of metering data.

CONCLUSION

In this work we have elaborated an electricity demand management scheme that can implement a structured set of priorities. These begin with the electricity consumer whose needs as notified to, or identified by, the smart control unit are paramount. In aggregate across a consumer population the flexibility in those needs yields an opportunity to shape demand which is used by the electricity supplier firstly to satisfy distribution constraints notified by the DNO and secondly to respond to generation variability and cost. Detailed simulation of this scheme has shown that in combination with a suitable regulatory framework it could deliver a "smart grid" solution that reduces the need for network reinforcement as demand rises.

Acknowledgments

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