MANAGEMENT OF DEMAND AND MICROGENERATION USING A RADIO BROADCAST OF BULK GENERATION EFFICIENCY

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ABSTRACT

A method for large scale management of electricity demand using a public radio broadcast is described. It is also suitable for despatch of micro generators such as CHP units. The broadcast consists of a signal indicating the expected average exergy loss of bulk generation in each half hour of the next day. Electrical appliances under management receive this signal and use it to place their electrical load (or CHP generator output) at times which minimise loss while meeting user requirements. Modelling results show how this method could reduce peak UK demand by 2GW.

INTRODUCTION

The need for demand-side management is increasing, because of the rising aggregate capacity of renewable generators such as wind turbines and photovoltaic panels that are embedded in electricity distribution networks. These are seen by networks as a negative load whose presence depends on the weather. This intermittent negative load will increase the variability of demand and hence drive up distribution costs unless active management of demand can mitigate the effect.

An established, but limited, technique for demand side management in the UK is the radio teleswitch system. This controls the switching times of electrically heated thermal storage radiators, using a digital signal carried within the BBC Radio 4 broadcast on 198 kHz. The radiators are switched on for a 7 hour period overnight when other demand is low; the radio control allows the switching times to be varied to assist balancing of supply and demand.

There is now potential to develop this system so that a much wider range of appliances, such as refrigeration equipment, heat pumps, tumble driers, etc. can be included. Particular benefit would be obtained if small and micro Combined Heat and Power (CHP) units could be managed so that their electrical output is available at times of peak demand. However, direct control of such a diverse population of appliances is clearly impractical; instead the broadcast signal should influence the operation of each appliance but allow user needs to take precedence.

So that consumers can be rewarded for participation in this form of demand management, "smart" metering that captures the time of day of electricity use is essential. This paper assumes that such metering, already common in several European countries, will become universal.

THE BROADCAST SIGNAL

It is envisaged that the signal needed for the purposes described above will be broadcast at about 23:00 hours each day, and stored by the receiving control unit associated with each appliance, for use the next day. Figure 1 below provides a simplified picture of the overall control loop.

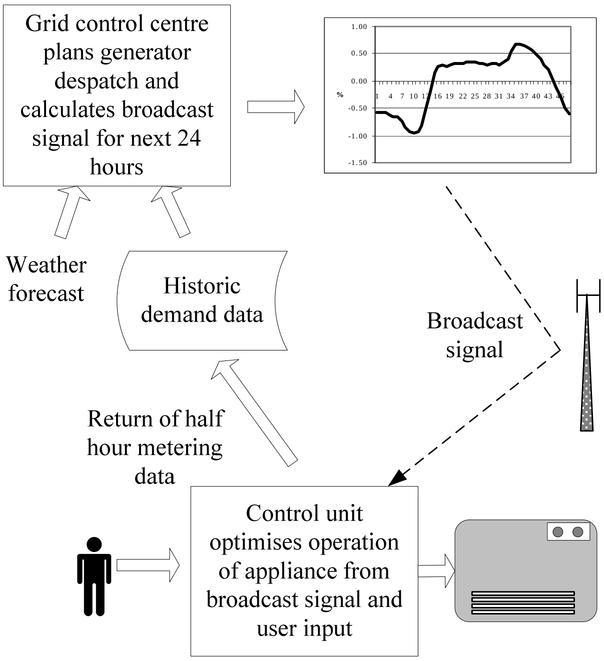

Fig. 1. Overall demand control loop

The signal must reflect expected demand, so that appliances can avoid peak times wherever possible, and also take account of the expected level of output from renewable generators. Where a wholesale electricity market is operated that can provide a price for each half-hour in the coming day, the profile of the day's prices could provide a suitable signal. However, reliance on a price signal is undesirable, for the following reasons:

- Not all countries have an efficient market at half-hour granularity.
- The use of a price signal encourages the consumer to

expect to pay a corresponding tariff, which limits commercial flexibility and may not be in the consumer’s interest.

- Wholesale prices are normally set nationally or internationally, whereas demand management should preferably operate on a regional or local basis.

This paper proposes that the signal should indicate the predicted average efficiency of electricity generation in each half hour of the next day, measured as exergy loss. Exergy is an extensive thermodynamic property of a system, also known as availability, which quantifies the ability of energy within the system to deliver useful work in accordance with the second law of thermodynamics. Exergy efficiency captures the extent to which that available work is successfully extracted. So an exergy loss signal will indicate, for each kWh of delivered electricity, the proportion that was lost of the available energy in the sources used to generate it.

The arguments for exergy loss as a signalled metric are set out in detail in [1]. In summary, it has the desired properties of increasing with rising demand, and falling with increased renewable generation, because:

- renewables and nuclear power have the highest exergy efficiency and are preferred in the order for despatch through their low (or zero) marginal cost of generation, while higher levels of demand are typically met using fossil fuel plant with lower efficiency;
- increasing demand causes higher exergy loss through network resistance (I^2R losses).

Exergy loss also provides a correct indication of the merit of CHP generation, and provides a reliable signal across a wide range of electricity generating and consuming devices allowing them to be integrated into a single system. The relationship with demand also ensures that it is a reasonably accurate proxy for a carbon intensity signal [2]. Table 1 shows exergy efficiencies for UK bulk generation plant from [3], and micro CHP exergy efficiency from [4].

Energy source	Exergy efficiency %
Coal	33.5
Oil	33.5
Natural gas	32.1
Nuclear	37.0
Hydropower	78.0
Gas fired micro CHP	51.9

Table 1. Exergy efficiencies of electricity generation

An exergy loss profile as envisaged for broadcast as a control signal is shown in Figure 2, for the UK national system on a winter weekday in 2005. Since the average exergy loss does not vary widely during the day, it is plotted as the deviation in percentage points from the mean for the day of 64.7%. Because there is little change during the day in the availability of generator capacity using each type of energy source, it tracks demand exactly.

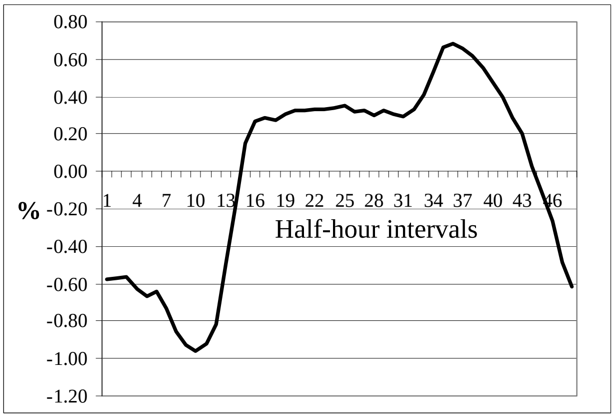

Fig. 2. Exergy loss (deviation from mean) for 1 Feb 2005

This behaviour will change as the proportion of renewables in the fuel mix increases. Figure 3 shows a modelled profile resulting from a scenario in which wind generation represents about 30% of plant capacity (corresponding to a typical contribution to the fuel mix of 9%). At the start of the day shown a winter anticyclone has caused the actual wind output to average about 6% of the fuel mix during the first 6 hours. During the day a fall in atmospheric pressure drives wind output to 14% of the fuel mix in the last 6 hours, resulting in a progressive improvement in the exergy loss profile. This is a realistic and potentially common scenario as shown in [5]. It can be seen that the optimised response required from controllable demand will be quite different from that under more settled climatic conditions.

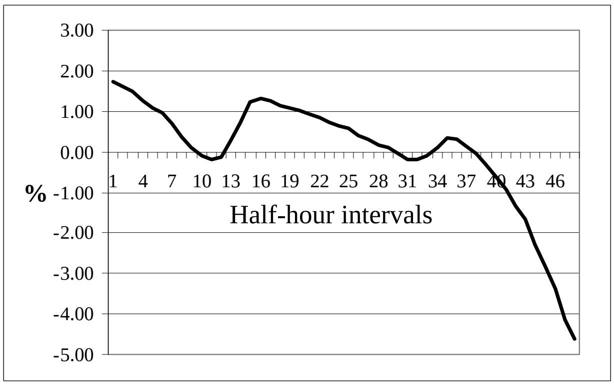

Fig. 3. Exergy loss (deviation from mean) with wind generation output rising from 6% to 14% of fuel mix

RESPONSE OF DEMAND TO BROADCAST

Thermal storage radiators and immersion water heaters are a good example of devices that could respond to this broadcast, because their thermal capacity allows the time when their electrical load is placed on the distribution network to be varied. Typically the consumer will enter the times when hot water or room heat is required into a control unit for one of these appliances. The control unit can then use the broadcast, acquired using a simple receiver integrated into the unit, to compute the optimum times to place its load (i.e. the times that minimise exergy loss). If a prediction of external air temperatures is broadcast along with the exergy loss data, the thermal storage radiators can adjust the energy charge they draw from the network to match the expected thermal load.

The operation of this scheme for control and management of demand and microgeneration has been modelled at a national scale for some plausible scenarios. Figure 4 shows the total UK national electricity demand in each half-hour interval for 1 Feb 2005, with the response of storage heaters in 200,000 homes, and 1,000,000 domestic immersion heaters, to the exergy loss profile (Figure 3) that would have been broadcast under this proposal. Where the demand from these appliances under control differs from that actually likely to have taken place on that date, the reduction in demand is shown. It can be seen that storage heater demand is delayed from its conventional overnight 7 hour timing to the early morning demand trough, which is also filled by water heating. Some water heating is also delayed from the early evening peak providing a useful reduction in demand.

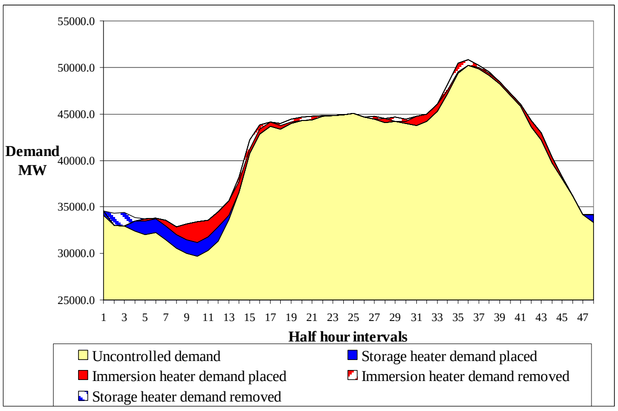

Fig. 4. Response of storage and immersion heaters to the exergy loss broadcast given in Fig.2

The benefits of this proposal when generation from renewable sources is fluctuating can be seen in Figure 5. This scenario employs the same population of appliances under control as Figure 4, but with the exergy profile resulting from a rise in wind generation as shown in Figure 3. Now storage heater demand is placed throughout the day, taking advantage of local exergy loss minima. The filling of the early morning demand dip is at a slope parallel to the falling trend of exergy loss, and water heating demand is moved from the morning and evening peaks.

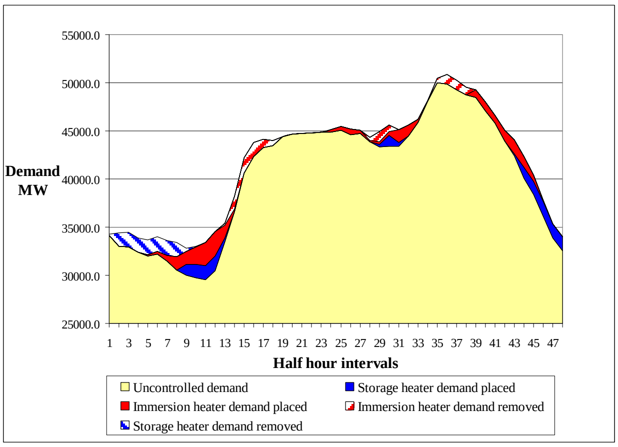

Fig. 5. Response of storage and immersion heaters to the exergy loss broadcast given in Fig.3

Results from modelling a CHP management scenario are shown in Figure 6. Because small and micro CHP are heat-led, they can be despatched by making minor adjustments, at times determined in response to the broadcast, to the room or water temperature set point that governs heat output. The modelling allowed adjustments of up to 1°C. The effectiveness of a slightly rising set point in moving electrical output to peak time is shown by practical demonstration in [4]. The demand and exergy loss profiles used in the scenario are same as Figure 4; the effect of the control is to move some generator output from the early morning (the diagonal shaded area) to the early evening peak (dark shading).

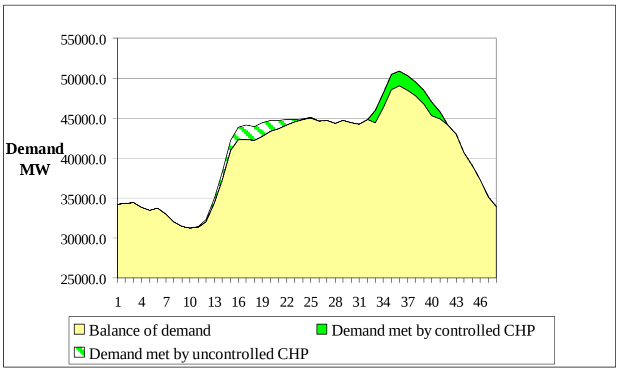

Fig. 6. Response of small and micro CHP to the exergy loss broadcast given in Fig.2

A population of 5,000,000 units with a 1kW peak electrical output was modelled; this is consistent with the UK micro generation scenarios for 2050 described in [7]. In practice this level of capacity is more likely to be reached with a smaller number of units and a spread of output levels to 5kWe and above as CHP is employed in business premises as well as homes. It is evident that if both immersion heaters and CHP were under control as shown in these models the early evening peak would be reduced by about 2.5 GW.

FURTHER PRACTICAL APPLICATIONS

Energy service provision

There is widespread recognition that the normal business model of energy utilities, payment by kWh, does not provide an incentive for them to promote energy efficiency. A preferred alternative encouraged by the European Union [6] is payment for energy services, such as a warm building and adequate hot water. The thermal storage radiators described earlier would be very suitable for this form of contract, but as currently used in the UK their limitation to 7 hours overnight charging and primitive thermostatic controls would prevent any commitment being given concerning comfort (i.e. room temperature) levels.

The technique proposed in this paper allows the overnight thermal charge to be adjusted to match the expected thermal load, and to be efficiently “topped up” during the day as necessary. A comfort commitment can be given with limited risk exposure to the energy utility. Similarly the operation of heat pumps, water heaters, and air conditioning equipment can be controlled in a way that ensures the user needs are met while taking account of the interests of the energy utility as conveyed in the broadcast information.

The advantage to the electricity industry of this form of contract is that the reward to the consumer for allowing their demand to be managed is the comfort commitment, rather than discounts on kWh. It is particularly appropriate for micro CHP, where the right to despatch the generator is valuable to the energy utility and will be acceptable to the consumer if balanced by a comfort commitment and protection from any extra fuel cost.

Plug-in Hybrid Vehicles

Hybrid petrol-electric vehicles which can take a battery charge from grid power are emerging as by far the most credible technology to mitigate the carbon emissions of road transport [8], and are likely to be the dominant type by 2020. This will present a challenge to electricity distribution networks to supply the additional power required, but will also provide a new opportunity for balancing electricity supply and demand by using the batteries of vehicles that are parked and connected to the electricity supply via a suitable AC/DC converter.

The battery charger for such a vehicle, if equipped to receive this broadcast, would take power from the grid at times of low exergy loss, i.e. low demand or high wind output. Normally this will occur overnight. Since the early evening demand peak necessarily occurs after people have arrived home in the evening, the residual battery charge from the return commuting journey could also contribute to meeting peak demand, as signalled by this broadcast, if the charger was designed to be bidirectional.

CONCLUSION

The urgent need to reduce carbon emissions will lead to radical changes in the patterns of electricity demand that distribution networks must deliver. These will arise from the rising penetration of embedded renewable generators, and also new demand sources such as hybrid cars. It is therefore essential that the technology for demand side management be improved.

A radio broadcast operating on a regional or local basis as described in this paper, when combined with smart metering, can provide a simple low cost control loop bringing demand management to any electricity consuming or generating device that can benefit from it.

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