NETWORK BENEFITS OF ENERGY EFFICIENT LIGHTING

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ABSTRACT

European energy directives have successfully promoted the substitution of more efficient compact fluorescent lights for traditional incandescent types; however, in the UK, these benefits have been largely annulled by an increased adoption of halogen spotlights.

At the same time, the discourse surrounding residential 'peak shaving' to relieve network capacity has typically focused on the shifting of demand, particularly using 'wet' appliances such as washing machines and dishwashers which are considered to be flexible loads.

The substitution of emerging light emitting diode (LED) technology for existing halogen fittings may have significant potential for peak shaving of a similar magnitude to that achievable with load shifting.

This paper analyses the relative merits of the approaches to peak shaving through the synthesis of high resolution demand profiles on low voltage residential feeders.

A residential demand model is augmented with recent UK lighting survey data and empirical power quality data measured from a range of lighting types. The substitution of lighting types is compared to the shifting of wet appliances in otherwise identical scenarios.

INTRODUCTION

Residential demand makes up approximately a third of UK electricity energy demand and notably around 43% of peak power demand [1]. UK government reports estimate that lighting services represent 17% of residential electricity demand [2].

In delivering this energy, 7.5% of all that is generated is attributed to losses, and 73% of these losses are attributable to the distribution network [3]. Because losses are proportional to the square of current flow, shifting loads off peak will also tend to reduce the total energy of losses.

With climate change policy now promoting new loads such as electric vehicles and the electrification of heating, there is concern about the potential costs of distribution system reinforcement. Peak capacity then is at a premium and the smart grid agenda has brought the distribution constraints into focus.

These factors suggest that peak reduction and improving load factors have a range of benefits in reducing system capacity requirements, reducing peak power demand and reducing losses

'Peak shaving' has become associated with load shifting and is on the whole considered independently from energy efficiency, which has seen policy largely focussed on measures to reduce space heating costs and the promotion of compact fluorescent lighting.

The Lighting Industry Association (LIA) conducted an extensive survey of residential lighting in 2007 and in 2010 [4]. The main finding of this work was that in the three year interval between surveys, whilst compact fluorescent bulbs had substituted some incandescent lighting, there was also a significant increase in the use of halogen down lights. Moreover, using simple lighting use models, these bulbs use roughly what has been saved by the use of compact fluorescent lights (CFLs)

Using a detailed bottom up model this paper compares the effects of lighting efficiency and load shifting interventions in reduce residential peak demand, and thus reduce system capacity requirements.

METHOD

Rather than developing another bottom demand side model, a framework has been developed that provides a generalized platform for the development of demand side models [5]. A key feature of the approach used is that the software is *data driven*, more specifically, the creation of the static model and its dynamic behaviour are almost entirely determined by data files which can be modified by the user. This is the converse of 'black-box' approaches, since all determinants of the load profile are explicit in the input dataset.

Using the data collected by the authors, individual appliances are modelled, after Capasso et al. [6], as opposed to using averaged profiles. Rather than using fixed values for active and reactive power flow, loads are modelled as impedances which respond to supply voltage. Since appliance loads such as fridges and ovens, are influenced by room temperature, and *vice versa*, simplistic heat transfer is modelled, after Pearce et al. [7]. In order to shed light upon the nature of power flow and losses on LV networks, cables are also modelled, after Guttromson et al [8].

Central to the framework is the Office of National Statistics Time Use Survey (TUS). Last updated in 2005, the TUS contains a snapshot of the daily life of thousands of households. Household occupants are modelled using the TUS diary data which enumerate the activities of household occupants. These diary activities are used to activate appliance models based on a set of 'narrative rules'. Table 1 shows example narrative rules and indicates how, using rules that include environmental variables, appliance related behaviour can be mimicked.

Table 1. Examples of appliance activation 'narrative rules'.

Activity	Rule	Action	Setting
Laundry	light < 50.0	light_kitchen	on
Laundry	rnd > 0.5	Tumbledryer	on
Laundry	rnd > 0.25	washingmachine	cotton40
Ironing	light < 50.0	light_kitchen	on
Ironing	1	Iron	cotton
Eating	light < 50.0	light_dining	on

A larger set of rules to activate all domestic appliances has been developed heuristically, and this now results in a good fit to national average residential demand profile (profile class 01), as well as appliance categories also having appropriate total annual energy demand [5].

The narrative rules now use parameters to describe the propensity of a light fitting to be used as 'mood lighting', and these result in some lights turned being on, if a property is occupied, irrespective of the activities being conducted. The results presented in the following section are based on a primary light in a room being turned on if the room is associated with a TUS diary activity. Other lights in the living room, dining room, kitchen, landing and hallway are defined as having a 50% percent chance of being a 'mood' light in the winter. Note that this assumption only seems valid for modelling winter demand.

Since it is possible to mimic household electricity demand in detail by using this framework, to examine the different approaches to peak shifting we can simply substitute the data that describe a specific aspect of the household.

For the peak shaving scenario, rather than attempting to mimic behavioural change, a set of 'wet' appliances was developed that allows settings to be deferred and started automatically. The wet appliances included washing machines, tumble dryers and dishwashers. The switching on of the appliances after peak is scheduled in a sequentially delayed manner to avoid all appliances being switched on together and thus causing a secondary peak. Peak is defined as 4.30pm – 9.30pm to ensure that almost no wet appliance activity is present at peak.
For the lighting technology substitution, the original LIA survey data is modified by a script and all bulbs of a particular lighting type are substituted. CFLs are assumed to use a quarter of the power of an incandescent and light emitting diodes (LEDs) a tenth of halogen equivalent, an approximation of current respective efficiencies. The base-case distribution of bulb fittings is shown in table 2.

Table 2. Base-case light fitting distribution.

Type\Watts	11	20	25	35	40	60	100
CFL	1911	298	81	31	546	720	104
Fluorescent	7	11	15	7	47	219	39
Halogen	78	227	136	128	988	155	34
Incandescent	65	81	198	38	1897	2351	390
LED	28	2	2	1	6	2	5
Total	**2089**	**619**	**432**	**205**	**3484**	**3447**	**572**

Using simple substitutions, as described, several scenarios have been developed to investigate different peak shaving options.

1) Base-case
2) Incandescent replaced by CFL
3) Halogen replaced by LED
4) Both 2&3
5) Peak shaving with wet appliances
6) All measures together.

These scenarios are executed for one winter weekday, with all other aspects of the model being identical. The distribution network topology and parameters data used to model the cables represent the network served by one secondary substation in Merton, south west London. Of the 400 metered connections on this network all are assumed to be non-electrically heated residential customers (known as profile class 01 in the UK).

RESULTS

Figure 1 shows the active and reactive power demand profile for the base-case scenario over 24 hours on a December weekday. The profiles run from 4am to 4am, corresponding to the TUS diary datasets.

The first observation is that, even after a reasonably large diversification of 400 homes, there is considerable variation in the instantaneous load on each phase. This variation is due to the propensity of high power loads to be on for short periods and the lack of averaging seen in half-hourly profiles.

Reactive power flow is low relative to active power and fluctuates between leading in the night and lagging during some periods of the day. In the model this is attributable to increased motorised appliances being used in the day, cancelling out the leading, capacative base loads.

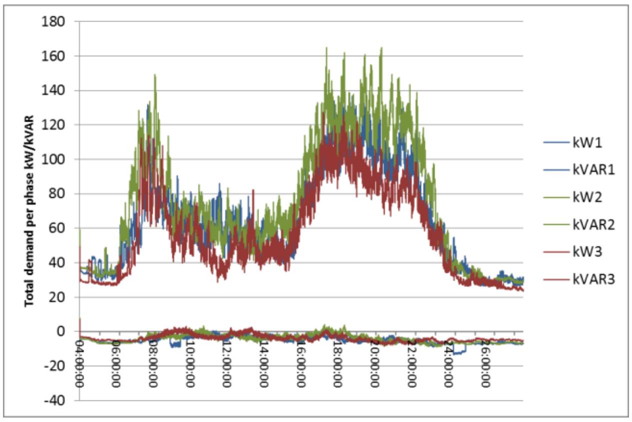

Figure 1. Base-case demand profiles for three phases (4am-4am).

Figure 2 shows the same scenario but with both the lighting techology substitutions (scenario 4). Here we can see a significant decrease in active power, but a significant increase in leading reactive power consistent with electronic lighting 'ballasts'.

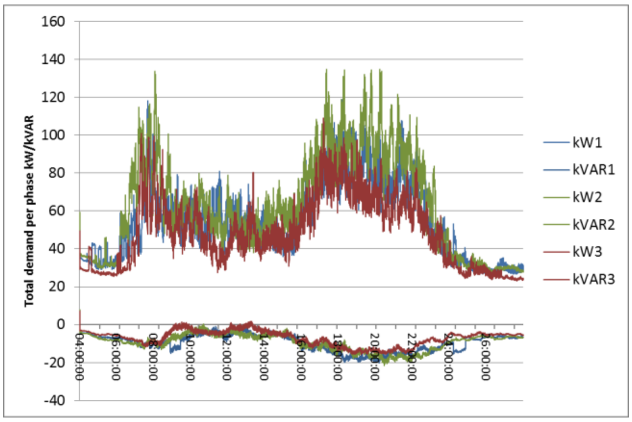

Figure 2. Scenario 4 demand profile for three phases.

The benefits of the two lighting substitution scenarios are very similar, as can be seen in Figure 3 which compares the individual measures and combinations. In this chart the y axis represents the reduction in load, and the recovery load from the wet appliances, where the deferred appliances start their programme.

It is clear from this comparison that the substitution of lighting technology has significant potential for peak reduction and this may be well in excess of that available from purely peak shifting activity. The CFL substitution is most effective in the evening peak, whereas the LED substitution most effective in the morning. This is consistent with halogen lights being prevalent in kitchens.

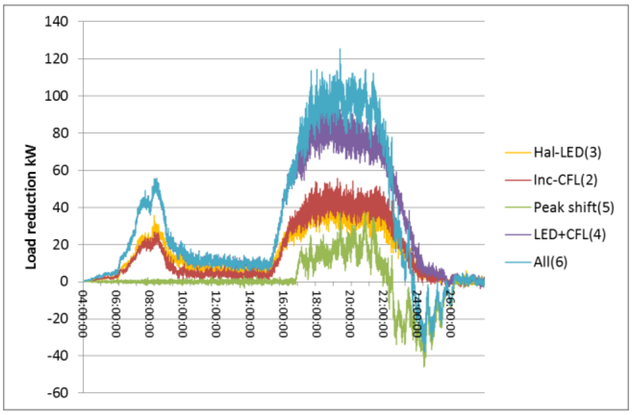

Figure 3. Comparative benefits of peak reducing measures (scenario numbers in brackets).

Figure 4 reflects the effect of both the efficiency interventions and peak shifting, compared to 'business as usual', and resulting in a significant 25% reduction in peak.

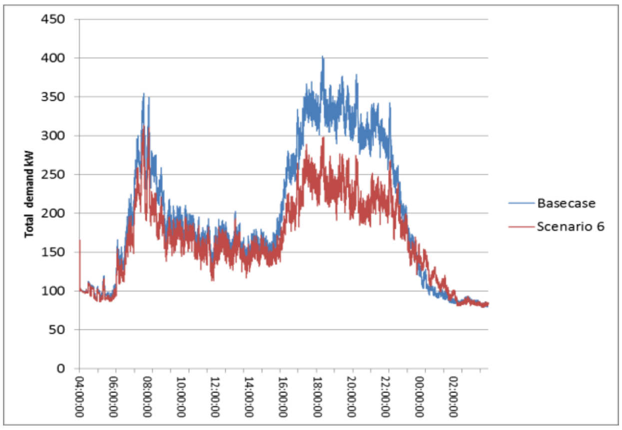

Figure 4. Total demand for base-case and scenario 6.

Returning to the subject of losses, we can see in Figure 5 that of this 100kW reduction of the peak, roughly 8% can be attributed to loss reduction.

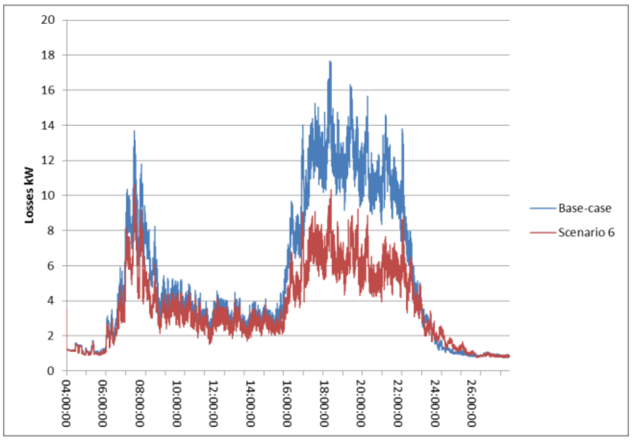

Figure 5. Live cable losses for base-case and scenario 6.

DISCUSSION

While the scenarios presented are for only one section of network on one winter day, there is clearly scope for peak reduction through the use of lighting energy efficiency. Where a load shifting approach to peak shaving would require significant infrastructure, be it smart metering and tariffs, or remote control, the efficiency approach has few technical barriers.

The barriers to light bulb substitution are however more subtle, related to human attitudes and social norms. There have historically been concerns about light quality from both CFLs and LEDs, but both technologies are improving, becoming more widespread and accepted. In parallel to this European Union policy continues to push lighting technology substitution with halogens bulbs clearly in their sights moving forward.

Loss reduction represents the ‘double dividend’ of peak reduction in both reducing peak power demand as well as total energy. The network used in this study was assumed to be balanced in connections per phase, but this is unlikely to be representative of the real system. It is likely that in a less well balanced system the benefits of peak reduction would increase, since the imbalance would increase losses.

It is also worth noting that the efficiency of CFLs may improve, or LED technology may become an attractive substitute for incandescent over CFL. In the latter case the benefit of swapping out incandescent bulbs would more than double. The modest scenarios presented were based on what is practical and in common practice today, as opposed to trying to make predictions about future technology developments.

In the UK, the responsibility of promoting residential energy efficiency was, in recent years, delegated to the energy retailers (suppliers) but the benefits accrue in part to the distribution networks who avoid system reinforcement.

CONCLUSION

The emphasis on load shifting in the energy policy discourse, especially in relation to ‘smart’ distribution networks has perhaps overshadowed the very real benefits of energy efficient lighting. The peak shaving benefits of load shifting appear to be less than the potential of lighting efficiency, and more options for efficiency are available than those which were tested.

It would appear that, over time, with continued pressure from EU policy, lighting efficiency will reduce peak lighting demand. Given the real benefits to the distribution network operators, the promotion of energy efficient lighting could be considered as a tool for network constraint management.

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