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THE INFLUENCE OF DIFFERENT TARIFFS SCHEMES ON ELECTRICITY CONSUMPTION FOR THE UK DOMESTIC BUILDINGS

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ABSTRACT

Electricity Suppliers in competitive electricity markets commonly respond to prices changes which are fluctuating over time, but most consumers respond to the price changes as reflected on their electricity bills. Almost all consumers pay fixed tariffs for their consumption without distinctions based on usage time, so these consumers have had no incentives to reduce their use during the peak times. This paper aims to analyze the influence of different tariff schemes on consumer behaviours in UK domestic buildings. A realistic half hourly electricity load profile for different types of UK households that based mainly on public reports and statistics has been generated. This load profile data were used to help calculate the expected change in consumers' bills under standard tariffs offered from different suppliers to what the cost of electricity would be under time varying tariff (economy7 tariff) and to estimate of how much consumers would shift their load in response to price changes without changing total consumption, for which the results are presented and discussed..

Index Terms— Tariff, electricity consumption, load profile

1. INTRODUCTION

The recognition of the pattern of energy uses of a house and the prediction of domestic load profile is a vital in order to match load shape to power generated, and also to predict the possible impact of any energy management action directly on the daily load profile. The usage of electrical appliances is associated to the occupancy period. The total energy load profile can vary significantly from time to time depending on number of occupants, their behaviours and the unoccupied period during the day. In the UK the domestic sector is accountable for almost one third of the total electricity consumption. It contributes the largest peak demand in winter season, which is hurting the available power infrastructure, and meeting the peak demands in winter is progressively more costly and high price spikes is seen [1]. The domestic energy consumption in the UK can be divided into three categories: space heating, domestic hot water, lighting and appliance. The usage pattern varies

depending on many determinants, such as weather, household composition, income, behaviour patterns of occupants; etc. The consumption per time interval is the sum of many consuming appliances. The load of a typical appliance connected to the grid is fluctuating over time and depending on time of usage. This results in a fluctuating electricity demand during a day and during a week.

Under competitive electricity markets condition, if rational electricity tariff to consumers is determined, consumers could be encouraged to modify style of their consumption in response of financial incentives. Consequently we can achieve the objective of making load in a more steady level and recovering the stability and efficiency of the power system. As one of power prices to consumers, TOU electricity tariff is extensively applied in many countries. Furthermore, it is one of significant tools of demand side management (DSM) which encourage consumers to adjust their consumption during the high demand periods [2]. Time varying tariffs offer smart off peak rates, but relatively high peak rates. TOU tariffs for domestic consumers were first begun in 1965 and led to a exceptionally significant growth of electric storage water heaters and the resultant growth of off -peak consumption [3]. In the UK; Economy 7 is the familiar scheme for domestic consumers. It is a cheaper night time electricity tariff which normally operates from midnight where seven hours of low tariff electricity at night.

For a Time varying tariffs to be valuable, advanced metering infrastructure (AMI) which carries capability to display real time prices .The availability of such information will allow consumers to respond o the variant in electricity tariffs. This is generally known as demand response [4].

There have been numerous investigations dealing with domestic electricity consumptions load profiles and electricity prices in the UK [5-12]. A monitoring campaign was undertaken by Newborough [5] where the energy demand data of 30 homes have been collected in order to modulate electricity demand emanating from individual dwellings to reduce the peak demand. A survey data among a sample of more than 1000 adults has been conducted and a questionnaire was designed in the south-east of England in order to collect information from consumers about environment, Ownership of appliances, Usage-patterns, and etc [6]. The result of this study, such as ownership level, and total energy consumption of

certain appliances are generally used when modeling of domestic energy is carried out for the UK. A simple method of formulating load profile (SMLP) for UK domestic buildings was presented by R. Yao and K.A. Steemers [7]. The input data of the model was based mainly on public reports and statistics, such as the composition of households and average energy consumption of appliances per capita. The UK average size household (3 persons) was selected as an example of the implication of this method.

Paatero and Lund [8] presented a method for creating domestic electricity load profiles at individual household level. It is based on a bottom-up model where the household load composes individual appliances/appliance groups. The input data of the model was based mainly on public reports and statistics. V.Hamidi and F. Li [9] presented a generalized tool to assess the responsiveness level among domestic consumers by studying load profiles for different domestic consumers which are composed of power consumption of end-use appliances and also showed the impact of different electricity tariffs on the load profile of domestic consumers. A 1992 study was carried out by the Electric Association in the U.K. stated the most of consumers favoured a TOU tariff, and modified their energy usage. As likely, energy usage was reallocated to the less costly off peak period, while the whole monthly consumption remained reasonably constant [10].

This paper focuses on generation of different households load profiles in the UK domestic buildings and shows the impact of different electricity tariffs on consumers' behaviours.

2. HOUSEHOLD AND PROFILES

The UK has a population of 61 million in 2008 and a total of 25 million households with an increase of almost 0.6 per cent on 2006. Since 1971 the population has increased by 5.0 million. The average household size is 2.4.

A realistic half hourly electricity load profile data for the UK domestic buildings excluding the heating and hot water systems has been generated. The space heating and hot water systems are assumed to be provided by means of natural gas.

This profile is based on the information and results of previous investigations and works that is available in public reports and statistics. The produced electrical load profile is based on engineering assumptions as to the type of appliances owned and lighting that are in the house and when the occupants are likely to switch them on. The different households have different lifestyle; consequently, the shape of total load profile will fluctuate from house to house and day to day. The inputs of electricity demand profile generator are:

- The Census Demographic data which available from the UK Office for National Statistics (ONS) [11].
- Average annual electricity consumption of certain appliances (kwh/day per capita or

household) and ownership level of appliances [6].

Table 1 list the type of households in the UK for the year 2008 [11] and table 2 lists the average energy consumption of appliances in the UK [6, 12].

Due to lack of information about occupancy pattern of households, eight scenarios which present the most common scenarios of household occupancy pattern in the UK were proposed based mainly on public reports, statistics and questionnaire data in order to generate realistic load profile for different consumers.

Table 1.Type of households

Type of Household	Percentage Share (%)
Single adult without children	15
Single adult with children	6
Single retired adult	15
Two adults without children	24
Two adults with children	19
Two retired	9
3 adults or more without children	8
3 adults or more with children	4
Total	100

Table 2. Average energy consumption of electrical appliances in the UK [6, 12]

Appliance	Av. Annual Cons. Per Household (kwh/day)	Av. Annual Cons. Per Capita (kwh/day)	Ownership level
Electric hob	1.33	0.39	55*
Electric oven	0.74	0.22	64*
Microwave oven	0.23	0.07	74
Refrigerator	0.82	0.33	53
Freezer	1.9	0.55	55
Fridge-freezer	1.9	0.56	58
television	0.91	0.27	97
Video recorder	0.3	0.09	76
dishwasher	1.72	0.48	16
W/Machine	0.8	0.2	88
Tumble dryer	0.78	0.28	49
Electric Kettle	0.78	0.28	97*
Iron	0.3	0.09	100
V. cleaner	0.15	0.04	100
Miscellaneous	1.1	0.33	100
Computers	0.5	0.3	75

2.1. Time of Use Probability Profiles

In order to create sensible load profiles, knowledge of occupancy patterns is required. The occupancy information was limited, so simpler assumptions have been made for each scenario. Although the demand for cold appliances normally varies during the duty cycle of the appliance, the assumption of constant load is assumed to be sufficiently accurate [13], the remaining appliances will have discrete events where the appliance is switched on and utilised. The usage time and probability of occurrence of each appliance was distributed randomly based on the occupancy period. The time of use probability is determined based on the questionnaire data survey analysis for a case study region. Figure1 shows the probability of first usage times per day for electric hob for the single adult household that resulted from questionnaire survey analysis. The lighting load was dealt separately.

Figure 1. Probability of first usage times per day for the hob for the single adult household.

Table 3. lists the most eight scenarios of likely occupancy period in the UK houses.

Table 3. Most common scenarios of likely occupancy period in the UK houses

Scenario	Household Type	Unoccupied Period
1	single working adult	08:30 to 18:00
2	Single retired adult	The house is occupied all the time
3	Single adult with children	08:30 to 13:30
4	Two working adults	08.30 to 18.00
5	Two adults with children	08.30 to 13.00 ~
6	Two retired	house is occupied all the time
7	Three adults or more without children	13:00 to 18:00
8	Three adult household with children, one occupant is retired.	The house is occupied all the time

2.2. Electricity Demand Profile Generator

A random profile of each individual appliance for each scenario was generated using Excel random profile generator which based on probability that enable us to predict the possibility of each consumer to run a number of appliances on a certain time of the day for different occupancy scenarios by describing the behaviour of each appliance which based on a probability between (0& 1). The usage time and probability of occurrence of each appliance was distributed randomly based on the occupancy period. The aggregation of the whole random profiles for all appliances will generate a daily consumption load profile for a known scenario. Fig 2 shows the framework of generating a typical single household load profiles.

The daily energy consumed by each appliance is calculated using one of the following equations:

$$E_a = N \times \sum E_{apc} \quad (1)$$

$$E_a = \sum E_{aph} \quad (2)$$

Where E_a is the daily energy consumption of household delivered by appliances; N is the number of occupants, E_{apc} is the appliance energy consumption per capita and E_{aph} is the appliance energy consumption per household.

The load profile for the whole community was calculated using the equation:

$$Load_{community} = \sum_{j=1}^8 E_{aj} \quad (3)$$

Where; $Load_{community}$ is the load profile for the whole community; E_{aj} is the half hourly load profile of household of type j .

Figure 2. Framework of producing a typical single household load profile

The average load profile for a single household for the whole community (eight scenarios together) is calculated by averaging the summation of the averages of all scenarios. The modeling results for the whole scenarios are shown in Fig 3.

Figure 3. Average half-hourly daily consumption for the whole scenarios

3. TARIFFS STRUCTURES

The consumers can help a utility by means of demand side management program if they are offered the right incentives.

Today in UK, most consumers have charged at standard electricity tariff for their consumption regardless of time of use. The standard tariff has currently two types: Standing charge tariffs and two tier tariffs. On the other hand, many UK suppliers have provided Economy 7 tariff. Economy 7 tariff is a cheaper night time electricity tariff which normally operates from midnight where seven hours of low tariff electricity at night. During the night period, electricity costs lower than the standard daytime tariff. To shift more energy consumption into the night, some main appliances such as, washing machines, tumble dryers, kettles or dishwasher cycle, electric boilers and heater might be configured to run during the night period tariff.

To examine the consumer's behavior in response to the tariff changes, consumer's quarterly electricity bill under different electricity tariffs schemes offered by five suppliers in the UK is calculated. Tables 4 list the standard tariffs plans offered by five suppliers (Source: http://www.ukpower.co.uk/home_energy/compare_electri

city, on 9th Jul 2010) and tables 5 lists the economy 7 tariff offered by one of the five suppliers [15].

Table 4. Economy 7 electricity tariffs by Sainsburys energy supplier

Brand	Rate
Band A (1000 kWh each year)	23.8p
Band B kWh	11.21p
Night kWh	5.03p

Table 5. Standard electricity tariffs offered by five suppliers

	npower	Atlantic Electric& Gas	Sainsburys Energy	British Gas	Scottish Power
Standing Charge	0	8.4210 p a day or 7.68p per quarter inc. VAT	0	0	13.301 p a day or 12.14p per quarter inc. VAT
Tier 1	14.91p/kwh for the first 728kwh inc. VAT	11.885 p/kwh inc. VAT	19.91p/kwh for the first 900kwh inc. VAT	23.5380p/kwh for the first 500 kwh inc. VAT	10.2250 p/kwh inc. VAT
Tier 2	13.90p/kwh for the rest inc. VAT	0	9.84p/kwh for the rest inc. VAT	9.172p/kwh for the rest inc. VAT	0

The Band A day rate will apply to a block of 1000 kWh each year (e.g. for an electricity bill covering three months the first 247 kWh will be charged at the band A rate, all extra day kWh will be charged at the band B rate). Night consumption will be supplied for a total of 7 hours between 10pm and 8am (actual times set by the local network operator) and these will be charged off the night kWh rate.

4. RESULT ANALYSIS AND DISCUSSION

A typical half hourly load profiles for UK households for different household types have been generated using statistical method. The daily energy consumption load profiles of electric appliances and lighting loads have been generated individually.

The average half hourly daily energy consumption of a each household type (scenario) is obtained by aggregating the electricity consumed by appliances and lighting at a specific time. The average magnitude of electricity consumption at 30 min intervals of a typical day for each household type was sought. These averages reflect the typical daily consumption for a given scenario. With availability of these results, different scenarios of consumer's bill under standard tariffs offered from different suppliers and economy 7 tariff were calculated in order to understand the benefits of economy7 tariff plan by changing the level of load shifts. due to consumers need to understand more about standard electricity tariff before choosing their suppliers, a

comparison between electricity bills for different consumers under standard tariffs offered by five suppliers has been made. Fig 4 shows how different standard tariff plans would affect consumers of choosing their suppliers, e.g if the consumer in scenario 7 is being supplied by the first supplier. So, £30 (19%) would be saved in his quarterly bill if he transfers his supply to fourth supplier.

Figure 4. Quarterly consumers' bills using different standard tariff plans from different suppliers for the whole scenarios

The electricity bills under a proposed demand side management by configuring some main appliances such as, washing machines, tumble dryers, kettles or dishwasher cycle, electric boilers and heater to run during night tariff period were calculated. The proposed percentage of the load shifted to night period is ranged from 10% to 50% without changing the total daily consumption. The percentage savings in quarterly consumer's bill using economy 7 tariff compared to standard tariff is listed in table 6.

Table 6. Percentage savings in quarterly consumer's bill using economy 7 tariff compared to standard tariff

% of load shifted to night period	Scenarios							
	1	2	3	4	5	6	7	8
	% Saving							
0	-17.9	-17.8	-10.9	-16.9	-11.1	-13.8	-11.0	-11.0
10	-16.7	-16.5	-7.6	-14.4	-7.7	-11.0	-7.7	-7.6
15	-16.1	-15.9	-6.0	-13.2	-6.1	-9.5	-6.0	-5.9
20	-15.4	-15.3	-4.3	-11.9	-4.4	-8.1	-4.3	-4.2
25	-14.8	-14.6	-2.7	-10.7	-2.7	-6.7	-2.7	-2.5
30	-14.2	-14.0	-1.0	-9.4	-1.1	-5.2	-1.0	-0.8
35	-13.6	-13.4	0.6	-8.2	0.6	-3.8	0.7	0.9
40	-13.0	-12.7	2.2	-7.0	2.2	-2.4	2.4	2.6
45	-12.3	-12.1	3.9	-5.7	3.9	-1.0	4.0	4.2
50	-11.7	-11.4	5.5	-4.5	5.6	0.5	5.7	5.9

As shown from table 6, the difference between consumer's e bill under standard tariff and the expected economy7 tariff bill was calculated for each household type (scenario). Positive difference indicates that the expected economy7 tariff bill would be lower than the actual standard tariff and thus indicates that the household is not expected to benefit under the new economy7 tariff. Similarly, negative differences indicate that the expected bill under economy7 tariff would be less than the actual tiered costs, and thus the household would be expected to benefit naturally under the economy7

tariff. The single household consumers who have small power consumption (scenarios 1,2 and 4) do not appear to benefit from adopting economy 7 tariff, as a result of that economy7 tariff can only be adopted for scenarios 3,5,6,7 and 8. From fig 5 it can be seen that with load shifting of 35%, economy 7 tariff can be adopted only if the daily consumption is about 11.5kwh and that with load shifting of 50%, economy 7 tariff can be adopted only if the daily consumption is nearly to 9 kwh.

Figure 5. Relation between consumed load and bill savings using different percentage of load shifting

The percentage savings in quarterly consumer's bill using economy 7 are shown in Table 7.

Table 7. Percentage savings in quarterly consumer's bill using economy 7

% of load shifted to night period	Scenarios					
	3	4	5	6	7	8
	% Saving					
0	0.0	0.0	0.0	0.0	0.0	0.0
10	3.0	2.5	3.0	2.1	3.0	3.1
15	4.5	3.8	4.4	3.2	4.5	4.6
20	6.0	5.0	5.9	4.3	6.0	6.1
25	7.5	6.3	7.4	5.3	7.5	7.6
30	9.0	7.5	8.9	6.4	9.0	9.2
35	10.5	8.8	10.4	7.4	10.5	10.7
40	12.0	10.0	11.9	8.5	12.0	12.2
45	13.5	11.3	13.3	9.6	13.5	13.7
50	15.0	12.6	14.8	10.6	15.0	15.3

5. CONCLUSIONS

In this paper the Influence of the changes in electricity tariffs on electricity consumption have been presented. A realistic half hourly electricity load profile for different types of UK households that based mainly on public

reports and statistics has been generated. The generated load profile has shown a reasonable agreement compared with the typical national load profile.

From the results it is shown that with elegant demand management (DM) and adopting economy7 tariff, the peak load can be modified to a suitable level to alleviate the insufficient of power supply. Moreover, consumers' bills can be reduced which would support them to adopt time varying tariffs without excessive discomfort to the consumer.

However, the savings depend mainly on some factors such as tariff structure and the load characteristics of the consumers. The consumers who have small power consumption don't appear to benefit from adopting economy 7 tariff. It can be seen by shifting the load to night tariff period, from 13 to 15 percent can be saved in the bill. The consumers need to understand more about their energy usage before making a precise decision about tariffs; as well they should understand the influence diverse schemes might have on behavior. The analysis helps to determine the suitability of adopting demand response in the domestic sector.

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