Evaluation of Domestic Electrical Demand and Its Effect on Low Voltage Network

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***Abstract* - Electrical demand in a house depends on various factors mainly being the user's behaviour and the rating of the appliances. Some researchers have used daily domestic electrical demand profile at half hour time resolution for the energy management. When data of half hour time interval is used for the analysis of on-site generation, it can lead to over/under - estimates of the proportion of generated energy used on site. As a consequence, this could lead to over/under-estimating in the import and export of power from and to the power grid. In this paper, domestic electricity use profile recorded at high time resolution of one minute is used to analyse the profile obtained at different time resolution and its effect on on-site generation.**

Daily load profile for summer and winter at time resolution of 30 minute is generated from a data set of 22 houses consisting data of a whole year which is then compared with the daily load curve obtained after diversity maximum demand from the literature. The generated daily load profile is then used to see effect on the low voltage network. For the analysis on the low voltage network, a typical UK low voltage network is developed in the Matlab/Simulink software.

***Index Terms* — Domestic load profile, Distribution network, Electrical load profile, Low voltage network.**

I. INTRODUCTION

Energy efficiency measures and application of emergent renewable energy technologies have made the energy end-user increasing important and influential on system operation. Electrical demand for a dwelling varies between households and spread of demand levels for different end-users over time varies over days and seasons, weekdays and weekends and loads coincidence. The breakdown of the use of electricity in a single household depends of mainly three factors: set of appliances in the household; the electrical rating of these appliances and the use of the appliances. The most unpredictable and complex among these three is the use of the appliances which highly depends on the behaviour of the occupants.

In most of the literature [1, 2] the time interval for each data of electrical load is half hour, which is the standard interval for load analysis and electricity trading in UK industry. Half hour resolution of electrical load is sufficient to show the load aggregated over the hundreds of customers such as at the point of distribution transformer. However, this aggregated load over of half hourly resolution tends to hide the high-frequency variations or spikes in loads over time in an individual building. In dwelling particularly, loads can vary greatly over a few minutes due to many appliances of higher rating and their pattern of use. On top of that, on-site generation, e.g. micro-combined heat and power (CHP), photovoltaic and micro-wind which have been very popular for dwellings, has increased the importance to understand the nature of domestic loads for appropriate energy management and supply/demand matching [3].

This paper compares the daily load profile obtained from two different time resolution 1 minute and 30 minute. Furthermore, the impact of using 30 minute time resolution load curve for the evaluation of on-site generation is analysed.

II. DATA SET

Data set of 1-min load (kW) were available from UK Data Archive for 22 dwelling in East Midlands of England between January 2008 and December 2009, with varying amount of data missing. Three different types of dwelling were included in the data set: detached, semi-detached and terraced with number of occupants varying from 1 to 6. Suitable assumption was made to replace the missing data in the data set such as, if any monthly, weekly, daily or hourly data was missing then data from the corresponding previous month, week, day or hours was taken to fill the missing data for instance, if the data of Monday in second week of May is missing then Monday of first week of May was taken to fill up the missing data.

III. DOMESTIC LOAD PROFILE AND TIME RESOLUTION

Electrical load on a house depends on various factors such as occupancy social status, size of house, number of occupancy, occupancy pattern, time of day and year, geographical location and ownership of appliances. It is the product of complex interaction between pattern of appliances used and the load themselves. For example, refrigerator is always connected but they are cyclic load whereas there are some loads which are constant. The residential electricity demand pattern can be generally characterised by a small base load with short peaks of high demand.

Different models for domestic electricity demand have been developed in the past. Richardson et al. [4] have developed a domestic electricity demand model based on the occupant time use data. Whereas, the model developed by Paatero and Lund [5] uses the appliances as the basis.

Among 22 houses, one house with typically high-demand and high base-load is selected. Different electrical appliances such as washing machine, electric shower, kettle, electric oven, microwave, toaster, dish wash, washer dryer along with timer were present in the selected house. A typical load profile for a day of February at 1 minute intervals and corresponding half-hour intervals is shown in Fig. 1. The same data when plotted at different time resolutions shows different load patterns which is clear from Fig. 1. Comparing these two profiles shows how half-hour interval data is smooth and smaller than the 1 minute interval data. A large load which operates for longer time such as a washing machine (operating in the early morning as shown in Fig. 1) was captured in the half-hourly interval whereas large loads with a short interval such as the spike after 8 and 21 could easily be missed.

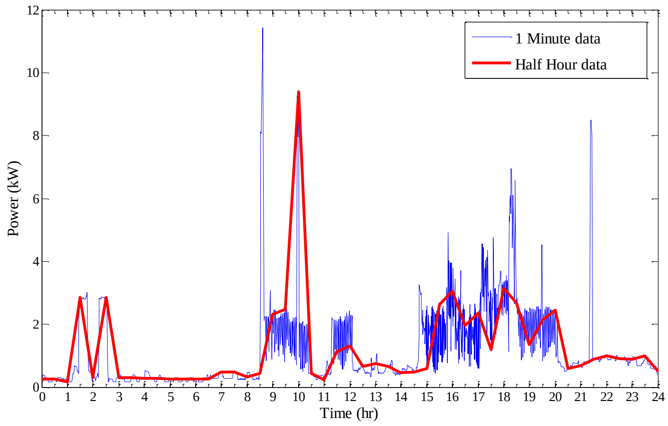

Fig. 1 Load profile at 1 Minute and 30 Minute time resolution

If assumed that house has an micro-combined heat and power which has electrical output of 1.5 kW (shown by black dot line in figure 2), half-hour data profile suggests that all the electrical loads in the house between 10:30 to 15:00 would be met by the micro-CHP and the surplus electricity can be exported or stored all time between the given period. While 1 minute data profile shows different picture of electricity import and export during the given time interval, all loads would not be met and there would be significant import of electricity from the grid between 11:00 and 12:00 and before 15:00.

Power consumed by same house on the same day using the two profiles (1 minute and 30 minute interval) give two different results.

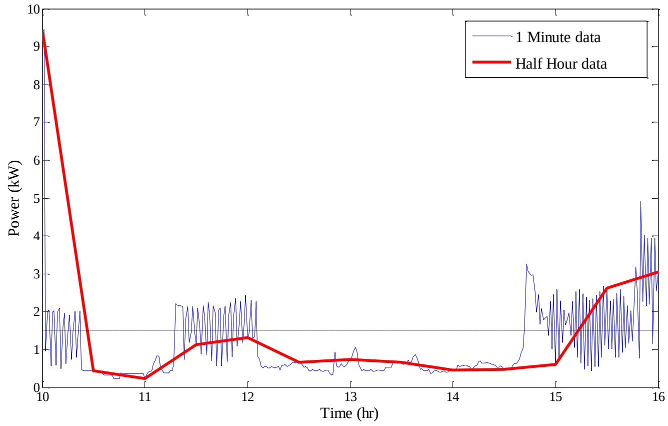

Fig. 2 Comparison of 1Minute and 30 Minute time resolution with 1.5 kW on-site generation

Similarly, if micro-CHP is assumed to operate for 24 hours then on the basis of 1 minute data load curve 38426.4 kWh of energy is supplied by the on-site generation whereas half-hourly load curve suggest 37317.6 kWh of energy supplied by the on-site generation. As a consequence of this the feasibility study of on-site generation could also be affected.

IV. Load Curve Comparison

From the available data set, summer load curve and winter load curve for 22 houses was obtained at an interval of 30 minute. The data set was first completing for a whole one year for all 22 houses by filling up the missing data with suitable assumption as mentioned in earlier section. Then mean daily curve for each month was obtained from the sum of all the house loads. In UK, June, July and August is consider as summer and December, January and February as winter so taking means of the respective months for corresponding seasons, summer load curve and winter load curves are obtained.

The obtained curves were then compared with the after diversity maximum demand (ADMD) daily load curves for summer and winter as shown in figure 3 and 4 respectively.

After diversity maximum demand is defined as "the maximum demand, per customer, as the number of customers connected to the network approaches infinity"[6]. The ADMD is often used for the design of electricity distribution networks where large numbers of customers are connected.

The comparison in the curves shows some similarity in the patter of the curves, loads are higher in the morning (getting ready for school/work) and in the evening (back from work/dinner time), least in the early morning (sleeping time) of a day and decreases at the night time. For summer, the load profile obtained from 22 houses is higher than the ADMD load curve and its other way for winter. This may be due to number of houses considered as ADMD load curve is obtained on the basis of load at the point of distribution transformer in the low voltage network which considers hundreds of houses. However, the main difference observed is the difference in time when the load starts to increase in the morning. From figure 3 it can be seen that the obtained curve start to increase after 5 a.m., which looks more realistic, where as in ADMD curve the increase in load starts after 7 am only.

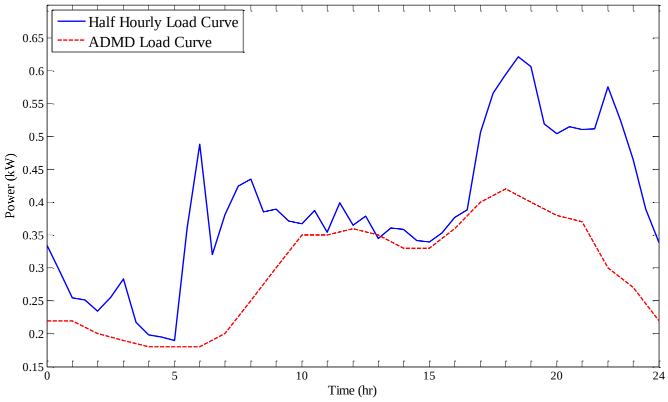

Fig. 3 Comparison of half hourly summer load curve

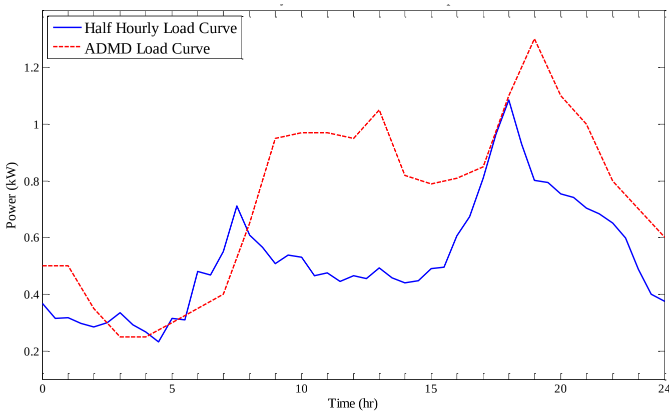

Fig. 4 Comparison of half hourly winter load curve

V. Effect on Low Voltage Network

To access the difference in the impact of the two load curves for winter and summer in the low voltage network, a typical UK distribution network, as shown in figure 4, which includes voltage levels between 33 kW and 400 V is used. The network includes a 33 kV (500 MVA) source as a grid supply point, which is connected to a substation consisting of two 33/11 kV transformers equipped with on-load tap changers. The substation supplies six 11 kV outgoing feeders and each 11 kV feeders supplies eight low voltage distribution substations. Each low voltage distribution substation consist of 11/0.4 kV (500 kVA) transformer which is an off-load transformer.

As the impact was to access in the low voltage side of the network, one of the six 11 kV feeder together with its connected loads were modelled in detail and other five were modelled as lumped load connected to 11 kV busbar. Similarly, one of the eight 11/0.4 kV substation was modelled in detail and others were modelled as individual lumped loads. Each 11/0.4 kV substation supplied 384 customer from its four outgoing feeders, resulting total load connected to 33/11 kV substation to be 384×8×6=18,432 domestic customers.

The above mentioned low voltage distribution network was modelled using Matlab/Simulink as shown in figure 5. 'Lumped 400V feeder of 11 kV' block in figure 5 is a subsystem of all lumped loads consisting of 11/0.4 kV substation connected to 11 kV feeder and 'low voltage feeder 400 V' block at right end of figure 5 is a subsystem in which detail of 400 kV feeder is modelled.

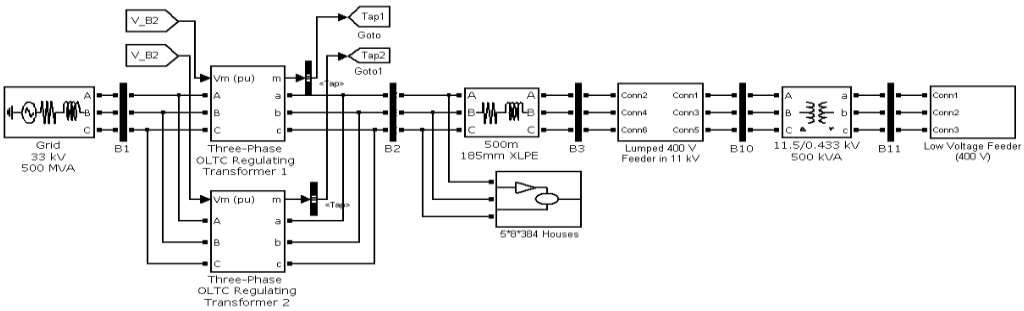

Fig. 5 Matlab/Simulink model of typical low voltage network in UK

The modelled low voltage network was simulated for 24 hours with summer and winter load curves obtained from the data set. Voltage at each busbar was measured during the simulation however, the voltage profile at the beginning and far end of 400 V feeder, i.e. busbar 11 (B11) and busbar 17 (B17), is only presented for summer and winter in Figure 6 and 7 respectively. The voltage profiles indicate that the voltage level remains within the statuary limits (1.06 p.u. and 0.94 p.u. for low voltage network) of the nominal voltage for the summer curve. In case of winter load curve, the voltage at busbar 11 remains within the limit but voltage at busbar 17 goes below the statuary limit around 18:00 when more loads are connected.

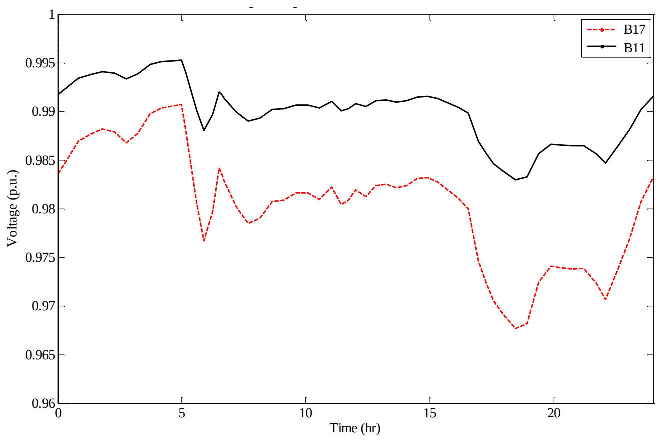

Fig. 6 Voltage profile at busbar 11 and 17 with summer load curves

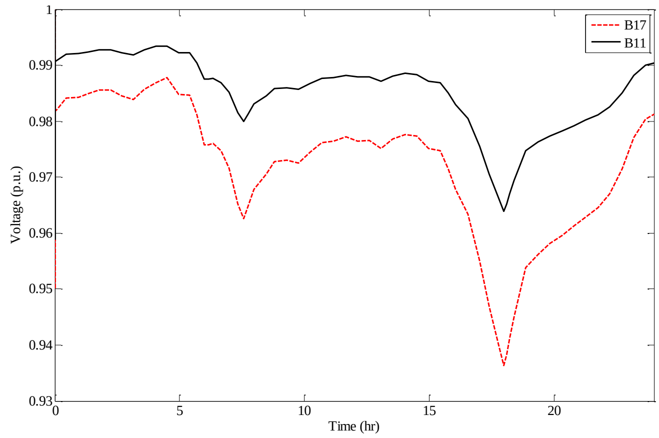

Fig. 7 Voltage profile at busbar 11 and 17 with winter load curves

VI. Conclusion

Domestic daily load profile of same house on same day with two different time resolution of 1 minute and 30 minute is presented in the paper. Disadvantages of using 30 minute time resolution daily load profile over 1 minute load profile is highlighted. Key point noted when using daily load curve with 30 minute time resolution is that it tends to hide loads with short interval and number of appliances which operates for short interval is high in dwelling. Along with that for on-site generation, using 30 minute load curve tends to under estimate the total amount of energy supplied to the house then using 1 minute load curve which further will affect the feasibility of installing on-site generation in the dwellings.

Summer and winter daily load curves were generated using the data obtained by monitoring the power of 22 houses. The curves were then compared with the respective seasonal ADMD daily load curve which shows the similarity of the patter.

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