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Review

Future residential load profiles: Scenario-based analysis of high penetration of heavy loads and distributed generation

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ABSTRACT

Electric load profiles are useful for accurate load forecasting, network planning and optimal generation capacity. They represent electricity demand patterns and are to a large extent predictable. However, new and heavier loads (heat pumps and electric vehicles), distributed generation, and home energy management technologies will change future energy consumption pattern of residential customers. This article analyses future residential load profiles via modelling and simulation of residential loads and distributed generations. The household base loads are represented by synthetic load profiles. Mathematical models are implemented for heat pumps, micro combined heat and power units, electric vehicles and photovoltaic systems. Scenario-based simulations are performed with different combination and penetration levels of load and generation technologies for different seasons. The results of the analyses show that with varying penetration levels of distributed generation and heavy loads, future residential load profiles will be more dynamic and dependent on multiple factors deviating from the classical demand pattern.

Contents

1. Introduction

Electric load profiles indicate variations in the electrical load with time. The profiles vary according to weather, seasons and customer load types (residential, commercial or industrial). Load data

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is important for accurate load forecasting, planning of electricity distribution grids and optimizing the generation capacity [1]. In a deregulated environment competing entities need to assess their load demands to accurately estimate the loads profiles for load balancing, bidding in the energy market, and for billing consumers who deviate from contracted schedules [2,3]. The electricity consumption in the residential sector takes a sizeable portion of the total national or regional electric power consumption. An analysis of twenty-seven European countries (EU-27) showed that energy consumption of the residential sector accounted for 24–26.7% of the total annual end use of energy in 2010 [4]. Additionally, the residential loads are changing in composition, capacity and complexity. In The Netherlands, the growth in residential distributed generation (DG), advancements in implementation of automated applications, and the potential large scale roll-out of smart metres contribute to the complexity of residential load profiles. Renewable energy accounted for 4% of national energy use in 2010 whereas the European target for renewable energy in the Netherlands is 14% in 2020. To stimulate renewable energy production the government has earmarked an annual sum of EUR 1.4 billion from 2015. Promoting the use of technologies that are cost effective and applying innovation policy to other technologies are some of the long-term approaches [5,6]. These developments generate uncertainties in the future energy supply systems and consumption patterns of the residential sector. At present, residential energy consumption data is difficult to obtain in The Netherlands due to customer privacy concerns. The use of models and simulations for estimating residential load profiles are novel practices to circumvent the privacy bottlenecks. However, existing residential load profile models are not suited for a reliable representation of the future electricity distribution needs [7].

2. Literature review

Previously published works highlight various models and techniques developed to generate present and future residential load profiles. A review by [8] classifies the techniques as “top-down” and “bottom-up” approaches. Each approach relies on different levels of input information and diverse simulation techniques, to provide results and analysis with different end-goals and areas of applications. The top-down approaches treat the residential sector as energy sinks and do not differentiate energy consumption of individual end-users. Clustering [9,10], forecasting [11], demand-supply scenarios and demand response policies [12] are examples of top-down methods applied to estimate load profiles. Another widely used method by the distribution network operators and energy suppliers is the synthetic load profiles (SLPs). They are useful for estimation of household load profiles particularly in situations of no or little historical data. Though, the shortcomings of these approaches are that information about individual peaks, load factors, and customers’ behaviours are overlooked.

Conversely, bottom-up methods account for the energy consumption and behaviours of individual end-users and extrapolate to represent neighbourhoods, districts or regions [8]. Probabilistic [13] and scenario-based [14] modelling approaches are examples of the bottom-up methods that have been implemented for generating future residential electricity demand and their impacts on the distribution grid. Other studies examine the effects of specific technologies such as heat pumps [15–17], electric vehicles [18,19], μCHPs [20,21], and PV systems [22–24] on residential load profiles and on the low or medium voltage grid. The downsides of bottom-up method are the high intensity of modelling, and the risk of missing appliance(s) to model.

The literature review showed novel attempts by researchers to understand the complexities and the challenges in generating residential load profiles, and to suggest solutions in mitigating current and future ones. While the literature review suggests that analysis of residential load profile is quite extensive, it is important to analyze load profiles for new residential neighbourhoods with different compositions and penetration levels of residential loads and distributed generations. This is the focus of this article. The rest of article is structured as follows: Section 3 introduces the approach and scope; in Section 4 presents the modelling of the loads and generations. In Section 5, simulations of scenarios for a number of households are presented; Section 6 focuses on the analysis of simulation results, while Section 7 summarizes the conclusions.

3. Approach and scope

Low energy houses are emerging concepts in the Netherlands. The zero-energy buildings (ZEB) concept is recently becoming popular with municipalities, commercial and residential stakeholders in The Netherlands as a way to enhance energy security and efficiency. It is an approach that involves making energy-efficient buildings, installation of distributed generations, and energy-efficient devices. Load profiles of such emerging neighbourhoods will deviate from the existing, classical, demand-pattern profiles. This article accesses the impact of distributed generation and heavy loads on the future residential demand pattern. The scope is limited to the residential environment involving 25, 50, 100 and 200 houses. These are average numbers of houses connected to typical distribution transformers in the Netherlands (see Table 4). The methodology adopted combines top-down (requires less modelling intensity and computational time) and the bottom-up (generally gives good results due to the inclusion of end-user behavioural models) approaches. Scaled synthetic load profiles represent base loads per household. A scenario-based approach is implemented for the analysis of different combination and varying penetration levels of heat pumps, μCHPs, electric vehicles and PV systems. The description, results and analysis per scenario are presented.

4. Modelling of residential loads and distributed generations

4.1. Base load

The base (non-deferrable) loads are defined as devices whose operations cannot be postponed to later or earlier time periods. In this article we define the base load to consist of power demand from all domestic appliances except heat pumps, μCHPs, electric vehicles and PVs. They are represented by the synthetic load profile (SLP) database for households without heavy loads and distributed generations in The Netherlands. SLPs are statistically determined load curves of representative residential customers and it is calculated with standardized load profiles and consumptions of the previous year expressed as:

$$\mathrm{SLP}(t) = \frac{E_{\mathrm{prev,year}}}{E_{\mathrm{avg,year}}} \times P_{\mathrm{standard}} \quad (1)$$

where $E_{\mathrm{prev,year}}$ is the consumption of the previous year (kWh); $E_{\mathrm{avg,year}}$ is the average year consumption (kWh); and $P_{\mathrm{standard}}(t)$ is the standard load profile in 15-min power values [W]. They are useful estimations of household load profiles and are comparable to measured data as illustrated by Fig. 1. Representative base (synthetic) load profiles for the winter, spring, summer and autumn periods for residential customers are as shown in Fig. 2. The selected SLPs for households without heavy loads (heat pumps and electric vehicles) and distributed generations (PV systems and μCHP) in The Netherlands.