Flexibility potential to reduce the peak load of small- and medium-sized enterprises

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George Rouwhorst[1] ✉, Rik Fonteijn[1], Arnoud Brouwer[2], Phuong Nguyen[1], Han Slootweg[1,2]

[1]*Department of Electrical Engineering, Eindhoven University of Technology, Eindhoven, The Netherlands*
[2]*Asset Management, Enexis Netbeheer, s-Hertogenbosch, The Netherlands*
✉ *E-mail: g.d.g.rouwhorst@tue.nl*

Abstract: Due to the energy transition, electric vehicles (EVs) and heat pumps (HPs) are penetrating the distribution network, which leads to an increase in (peak) demand. Additionally, the energy transition is also causing an increasing share of solar photovoltaic (PV) into the distribution network. Therefore, time consuming and expensive network reinforcements become necessary to prevent network congestions if no alternatives are available. Two of these alternatives considered in this study are demand-side management to unlock flexibility on the demand side and electrical energy storage. First, this study introduces a method to synthesise the load profile of small and medium-sized enterprises if EVs, HPs or solar PV are included. Finally, a theoretical method is introduced to quantify the flexibility provided by EVs and HPs to reduce the peak load and a theoretical method to quantify the impact of home batteries to reduce the peak load. The methods are used for a case study as part of the Dutch pilot project 'Community-flex Bedrijvenpark Zuidoost' in the city of Groningen.

1 Introduction

1.1 Background

The current energy transition is leading to an increase of renewable energy sources (RESs) penetrating the electricity network and an increase in demand due to the electrification of mobility, heating and cooling.

Due to the intermittent properties of RES (solar photovoltaic (PV) and wind), it is harder to control the electricity generation which limits the flexibility on the generation side to balance supply and demand. Additionally, RESs are connected to the distribution network, unlike conventional large-scale generators which are usually connected to the transmission network. Therefore, this type of generation is also referred to as distributed generation (DG) [1]. As a consequence, the electricity flows in the distribution network become bidirectional. If a surplus of electricity is generated, this could lead to network congestions. Electric vehicles (EVs) and heat pumps (HPs) are a sustainable alternative for conventional vehicles and boilers running on fossil fuels. As a consequence, the demand is expected to increase, especially during peak demand, which could lead to network congestions.

Both developments together have an impact on the local match between supply and demand. On an annual time scale, the electricity generation of solar PV is relatively high during summer, while the demand is relatively low. During winter, the demand is relatively high, while the electricity generation by solar PV is relatively low which leads to an increasing change of congestions. On a daily time scale, the generation profile of solar PV correlates strongly with the load profile of a small and medium-sized enterprise (SME) which reduces the change of network congestions [2].

Traditionally, the peak load is the main driver for managing the network -and connection capacity. Therefore, expensive and time-consuming network reinforcements are expected to be necessary to prevent network congestions. The current developments in measurement technologies enable the distribution system operators (DSOs) to monitor and control the distribution network more efficiently and at lower costs allowing alternatives to manage the network- and connection capacity. Such a network is often referred to as a 'smart grid'. One of the alternatives is demand-side management (DSM) which aims to unlock flexibility from the demand side. In this case, consumers are stimulated to shift a part of the peak demand towards periods of lower demand and if RESs are present, towards periods of surplus electricity generation. Another alternative is the application of electrical energy storage (EES) to reduce the peak demand by charging the EES technology during periods of low demand and discharging this EES technology during periods of peak demand. If RESs are present, EES can be also applied to reduce the mismatch between supply and demand and thereby related congestions by storing surplus generated electricity to be used during periods when demand exceeds generation. However, EES technologies are still rather expensive which limits the applicable capacity. Therefore, measurement technologies allow to optimise the charging pattern to enable an effective integration into the electricity network [3].

1.2 Problem definition

Until now, several Dutch pilots have been performed which focus on the availability of flexibility on the domestic level [4]. However, little is known about the flexibility potential of SMEs. Due to the difference in the typical load profile between both groups of customers, the available amount of flexibility is expected to be different. Therefore, this paper first introduces a theoretical approach to (a) model a typical load profile for an HP, a charging station for EVs and solar PV at an SME which enables to analyse of the impact of these loads on the measured base load of an SME. Secondly, a theoretical approach is introduced to (b) model these typical load profiles with flexibility and a battery to reduce this peak load. In collaboration with the pilot project 'Community-flex Bedrijvenpark Zuidoost', a case study is performed using the introduced models with historical data from smart meters retrieved from five SMEs located in one street of a business park in the Dutch city of Groningen.

2 Methodology

2.1 Charging station

Every charging station is assumed to be a private charging station. The charging loads are synthesised in two ways. The first approach is based on publicly available charging characteristics provided by ElaadNL in the Netherlands from 2016 to 2018 [5]. The average duration of each charging event is 2.5 h and the maximum charging power 20.0 kW. Additionally, ∼70% of the EVs being charged are plug-in hybrid EVs (PHEVs), while 30% are full EVs (FEVs) in 2019. A typical charging rate of a PHEV is 3.7 kW, while a typical charging rate of an FEV varied between 3.7 and 20.0 kW. To construct the load profile, a random variation between 3.7 and 20.0 kW is assumed for each charging event of an FEV. All the EVs are connected from 09:00 to 17:00 with a random variation in time of arrival from 08:30 to 09:30 and time of departure from 16:30 to 17:30 representing a typical Dutch working day. The second approach makes use of measured charging loads from six charging stations which are measured at the office of ElaadNL during January 2019. For the case study, one of each type of charging station is installed at an SME.

The charging load with flexibility is synthesised by incorporating the condition that the first type of charging station avoids simultaneously charging with the second type of charging station. This is only possible if the connection time of the EV connected to the first charging station is longer than the related charging time.

2.2 Heat pump

The temperature boundary of the HP is defined as 0.5°C higher and lower than the temperature set, which means that the HP switches on if the temperature drops below the lower boundary and switches off if the temperature exceeds the upper boundary. The COP of the HP is approximated as 3.5 if the temperature exceeds 10.0°C. The COP drops to 3.0 if the temperature drops between 10.0 and −1.0°C and further down to 2.5 if the temperature drops below −1.0°C. The operation cycle of the HP is defined by the temperature boundary and the temperature inside. The temperature inside is calculated every 5 min using the thermal heat supplied by the HP, heat loss and heat gain of the building. The heat loss of each building includes thermal and ventilation losses. The heat gain includes internal heat and solar gain. For the case study, the temperature is set to 20.5°C during office hours, based on the average setting for heating in the Netherlands [6]. The temperature setting for cooling is 23.0°C based on common practice in the Netherlands. Out of office hours, the temperature setting is 19.0°C. The minimum power of the HP is dimensioned based on the minimum power required to heat the specific building within the defined temperature boundary of the HP during the coldest period in the Netherlands in 2019.

The load profile with flexibility is synthesised while the HP aims to operate if the load is relatively low and remain off if the load is relatively high while keeping the temperature within the defined temperature boundaries. The flexibility of the HP is implanted using two conditions. Firstly, the HP is allowed to preheat the building an hour before regular office hours if the load is low. Secondly, the temperature boundary is increased from 0.5 to 1.0°C above and below the temperature set to increase the time interval before the HP has to switch on or off. During operation, the HP is allowed to switch between on and off before one of the boundaries is reached.

2.3 Solar PV

A generation profile is synthesised using the online available tools ‘Zonatlas’ and ‘PVWatts Calculator’ [7, 8]. ‘Zonatlas’ estimates the capacity of solar PV which can be installed on the roof of an SME. The first scenario estimates this capacity based on the available amount of surface area. The second scenario estimates the capacity based on the annual electricity consumption of the SME. Subsequently, ‘PV Watts calculator’ synthesises an hourly generation profile per kWp based on the postal code. Together, a generation profile of any SME is constructed for both scenarios.

2.4 Electrical energy storage

EES is applied in two different ways. During summer time, it is used to store surplus generated electricity by solar PV (charge) which is fed back into the electricity network during the night (discharge). During wintertime, EES consumes electricity during the night (charge) which is used to supply electricity back to the electricity network during periods of peak demand (discharge). For the case study, the EES technology studied is a home battery installed behind-the-meter which has a capacity of 13.5 kWh and a charge and discharge rate of 7.0 kW [9].

3 Results

The load profiles are synthesised as described in Section 2 during a time period of 1 year for the five SMEs from the case study. The graphs show a daily baseload profile measured by the smart meter from one of these SMEs with their related connection capacity.

3.1 Charging station

Fig. 1 shows the synthesised load profile if two charging stations are installed. The graph indicates that the peak load of this SME exceeds its connection capacity due to these two charging stations. However, if the EVs are charged with the defined flexibility conditions, a part of the peak load is shifted to the afternoon and as a consequence, the connection capacity is not exceeded. In general, the peak load reduction of the five SMEs varied between 10.6 and 29.6% if the whole time period is considered. The peak load reduction could be improved further if both EVs are connected for a longer time period than their charging time because the EV with the largest charging power is always able to be shifted to the period of lower demand. In the applied model, it is assumed that only the EV connected to the first type of charging station can be charged with flexibility.

3.2 Heat pump

Fig. 2 shows the synthesised load profile on a winter day based on an HP with a power of 12.0 kW. In this case, the connection capacity is not exceeded. If the whole time period is considered, the peak load reduction varied between 0.6 and 5.3% for the five SMEs if the HP is operated using the defined flexibility conditions compared to the case without flexibility. The flexibility of each SME is limited by the rate in temperature drop if the HP is turned off in combination with the

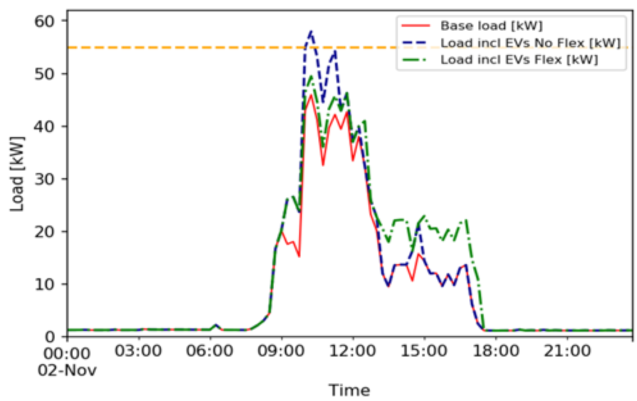

Fig. 1 *Measured baseload (solid) with two charging stations without flexibility (dashed), with the flexibility (dash dotted) and its related connection capacity (dashed)*

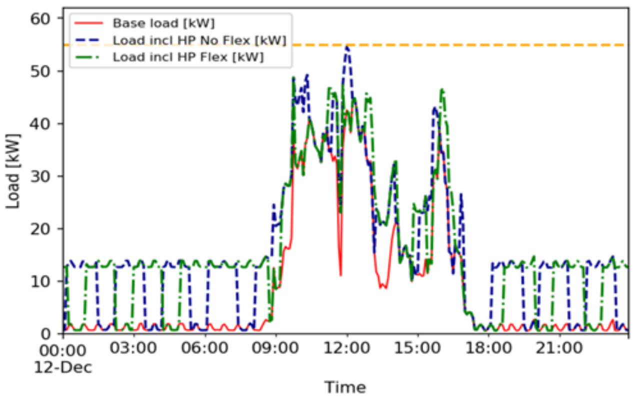

Fig. 2 *Measured baseload (solid) with an HP without flexibility (dashed), with the flexibility (dash dotted) and its related connection capacity (dashed)*

shape of the baseload profile, which determines the extent of the 'rebound-effect'. A rather flat baseload profile limits an effective application of flexibility because varying the operation time of the HP will only postpone the time of the peak load.

3.3 Solar PV

Fig. 3 shows the net consuming load profile on 24 May if a total of 44.1 kWp is installed on the roof of this SME in both defined scenarios. The terms 'positive' and 'negative' are used to distinguish the direction of the electricity flow. The positive peak load is reduced significantly due to the matching generation and load profile. However, the positive peak load reduction is smaller if the whole time period is considered due to the seasonal mismatch described in Section 1 and over all SMEs varied between 7.0 and 12.6% in both scenarios. On the contrary, the negative peak load increase is significantly larger which varied between −20.4 and −45.0 kW in scenario 1 and −9.2 and −45.0 kW in scenario 2 (the negative peak load of the initial baseload is assumed to be zero).

3.4 Electrical energy storage

Fig. 4 shows the synthesised load profile if the defined home battery is installed on a winter day. In this case, the battery can reduce the positive load during working hours with a maximum charging power equal to the maximum discharging rate.

The positive peak load reduction of the five SMEs varied between 8.3 and 14.9%. On a day with much electricity generation, the synthesised net consuming load profile of Fig. 3 is hardly unaffected, because the battery is already fully charged in

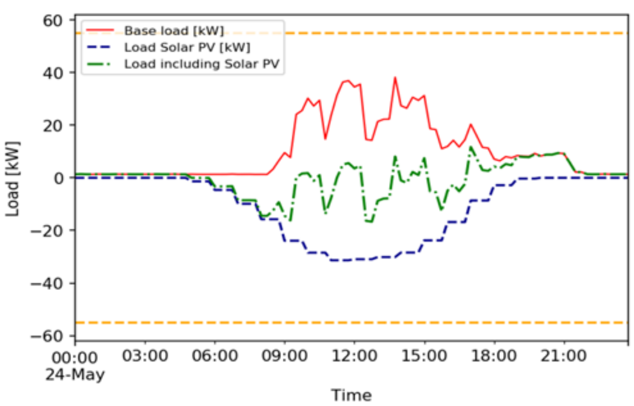

Fig. 3 *Measured base load with the generation profile of solar PV (dashed), netload profile (dash dotted) and its related connection capacity (dashed)*

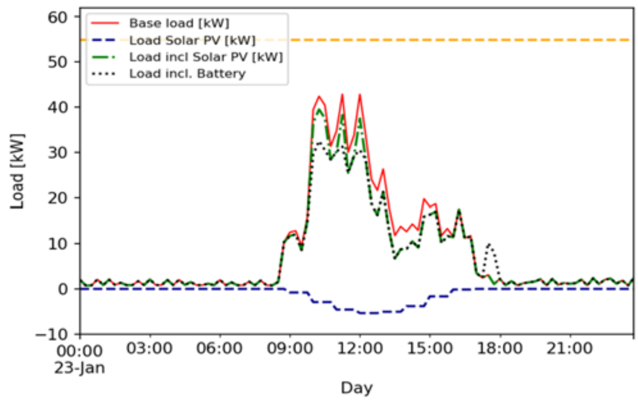

Fig. 4 *Measured baseload (solid) with the generation profile of solar PV (dashed), net consuming load (dash dotted), netload including battery (dotted) and its related connection capacity (dashed)*

both scenarios before the afternoon when the electricity generation is the highest. Thus, the battery is too small to reduce the negative peak load during the whole time period.

3.5 Connection costs

The connection costs of the related customer may increase if the connection capacity is exceeded due to the increasing peak load. The smallest connection capacity, provided by the responsible DSO of the area where the SMEs of the case study are located, is 18 kW. Larger connection capacities vary up to 25, 35 and 55 kW. If the peak load remains below 55 kW, the maximum financial benefit is € 1778.04 based on the tariffs of the same DSO in 2019 which is the difference in connection costs for a connection up to 55 and 18 kW. However, the connection costs do not increase if the peak load remains below the upper boundary of the current connection capacity [10]. If the peak load exceeds 55 kW, the connection costs increase per kW. These connection costs consist of the annual fixed costs (€614) and variable costs which are determined based on the annual peak load (20.38 €/kW) and monthly peak load (1.42 €/kW) [11]. For the SMEs studied, the reduction of connection costs varied from €117.60 up to €754.79 if the cases without an increase in connection costs are excluded.

4 Conclusion

This paper proposed a theoretical approach to analyse the impact of an HP, charging stations and solar PV on the load profile of an SME. Based on this approach, the theoretical potential to reduce the peak load by application of flexibility and a home battery is analysed.

This approach is applied to a case study using the baseload measurements of five SMEs. This case study indicated that the impact of flexibility on the peak load of these studied enterprises varied significantly for each load and SME. Nevertheless, the case study indicated that the relative peak load reduction due to charging of EVs is generally larger (10.6–29.6%) than the peak load reduction due to operating an HP with the flexibility (0.6 and 5.3%) which is strongly determined by three factors. First of all, if the connection time relative to the charging time of the EVs is increasing, the possibility to shift the charging load to other time intervals increases. Secondly, if the temperature drops inside the building are decreasing due to better insulation, the potential impact of flexibility increases as well. Finally, if the shape of the baseload profile is getting more constant over time, the potential impact of flexibility is decreasing. For the application of a home battery, the case studied indicated that a home battery can reduce the positive peak load up to 14.9% depending on the baseload profile of the SME. However, the home battery is too small to reduce the negative peak load in both considered scenarios.

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