Smart EV Charging Systems to Improve Energy Flexibility of Zero Emission Neighbourhoods

A State-of-the-Art for Norway

Åse Lekang Sørensen, Igor Sartori and Inger Andresen

Abstract The increased use of electric vehicles (EVs) calls for new and innovative solutions for charging infrastructure. At the same time, it is desirable to improve the energy flexibility of neighbourhoods. This paper presents state-of-the-art for smart EV charging systems, with focus on Norway. Norway is a leading market for EVs, with more than 110,000 EVs and 2000 charging stations. The paper describes how charging stations can interact with the energy need in buildings and neighbourhoods, local energy production and local electric and thermal energy storage. Examples of commercial smart EV charging systems are described. Smart EV charging systems have the potential to improve energy flexibility in a Zero Emission Neighbourhood (ZEN). Such EV charging systems can also interact with heating loads in neighbourhoods. Piloting of new technologies and solutions can provide more knowledge about smart EV charging systems, and how they can participate in matching energy loads in buildings and infrastructure with local electricity generation and energy storage.

Keywords Zero emission neighbourhoods · Energy flexibility · Flexible heating loads · Smart charging systems · Electric vehicles

1 Introduction

1.1 Background for the State-of-the-Art Study

The increased use of electric vehicles (EVs) calls for new and innovative solutions for charging infrastructure. At the same time, it is desirable to better match the energy needs in buildings and infrastructure, with local energy generation and energy storage.

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An energy flexible neighbourhood manages the local energy demand, energy production and storage capacity according to local climate conditions, user needs, grid constraints and prices. Flexibility is embedded in both thermal and electric systems and in the interplay between them. Flexibility can further be made available outside the neighbourhood to the grid.

This article describes state-of the-art for smart EV charging systems, with focus on Norway. Norway is a leading market for EVs globally [1], in terms of market share. In 2016, EVs had a 29% market share in Norway [1]. By May 2017, there are more than 110,000 EVs and 2000 charging stations in the country [2, 3].

The study aims to explore if smart EV charging systems can play a role in the pilot areas of the Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN Centre) [4]. The article is a first step towards answering the following questions: (1) How does the energy need for EV charging and charging profiles fit with the energy need and energy production in a neighbourhood? (2) How can a smart EV charging system be part of an energy management system which improves energy flexibility of a building and a neighbourhood? (3) Which goals and technologies demonstrated in smart EV charging systems today, can be relevant for the ZEN pilot areas?

The ZEN Centre is a new Centre for Environment-friendly Energy Research from 2017, funded by the Research Council of Norway and 34 partners [4]. The main objective of the ZEN Centre is to develop knowledge, competitive products and solutions that will lead to realization of sustainable neighbourhoods, that have zero emissions of greenhouse gases related to their production, operation and transformation. There are seven pilot areas in the ZEN Centre, where new technologies and systems will be implemented and evaluated. The Centre aims to speed up decarbonisation of existing and new building stock, use more renewable energy sources and create positive synergies among the building stock, energy, ICT, mobility systems and citizens.

1.2 Smart EV Charging Systems

The term “Smart” is used in a number of ways, as exemplified in this chapter and in Chap. 2.4. The added value of the smart-term varies from case to case, and it is therefore difficult to give a general definition of “Smart EV charging systems”.

The “Global EV Outlook 2017” [1] describes that as the number of EVs increases, charging could have a sizeable impact on the capacity required by the grid at certain times and locations. At the same time, EVs are well suited to promote synergies with variable renewables. If charging practices strengthen demand-side management opportunities, EVs could allow a greater integration of various renewable energy sources in the power generation mix. Further, the report points out that large-scale electric car charging and demand response will require joint optimisation of the timing and duration of recharging events, the modulation of power delivered by charging outlets and may involve a reliance on bidirectional Vehicle to Grid (V2G) solutions.

The Platform for electro-mobility in the EU states that "Smart charging of electric vehicles should benefit EV owners by reducing their electricity costs in return for the enhanced grid stability and reliability" [5]. Their definition of Smart charging is [6]: *Smart charging consists of adapting EV battery charging patterns in response to market signals, such as time-variable electricity prices or incentive payments, or in response to acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase (grid to vehicle) or energy injection (vehicle to grid) in organised electricity markets or for internal portfolio optimisation*.

Smart charging systems can have several aims, depending on the preferences of the operator. For example, EnergyVille [7] describes three scenarios for the management of a charging process: (1) Peak shaving scenario: Charge when the grid capacity is high (off-peak), or manage the simultaneous charging of several EVs in the same street or car park, by spreading their demand over time; (2) Renewable scenario: Charge when the availability of renewable energy from sun and wind is high; and (3) Balancing scenario: Keep demand/supply balanced. In each scenario, it is guaranteed that the EV will be charged by a certain time, and to the level requested by the owner.

EV flexibility services can be defined as a power adjustment maintained from a particular moment for a certain duration at a specific location [8], characterised by: (1) the direction, (2) the power capacity, (3) the starting time, (4) the duration, and (5) the location. If EV is not V2G capable, the flexibility direction is always the same.

Table 1 describes some control strategies and goals for smart EV charging systems, often found in descriptions of such systems. The possibilities are sorted from low to high "smartness". Methods to achieve intelligent control of charging can vary.

2 Smart EV Charging Systems to Improve Energy Flexibility

2.1 Energy Demand for EV Charging and Charging Profiles

Typical power use during EV charging in a household or commercial building is shown in Table 2. In Norway, the power is typically 2.3 kW when using a household power plug and 3.6 or 7 kW when using a Type 2 connector [9]. For normal charging, Type 2 connectors (EN/IEC 62196) are recommended [10]. However, household sockets are still frequently in use, especially in households. Semi fast chargers are typically 22 kW and fast chargers 50 kW or above [9].

For fast charging, the ten most popular EVs in Norway use CHAdeMO (44–100 kW DC), Combo 2 Charging System (CCS2) (40–50 kW DC) and Tesla supercharger (135 kW DC) [2]. Fast charging stations have fixed external chargers, according to Mode 4 in the standard IEC-61851-1.

Table 1 Examples of common control strategies and goals for smart EV charging systems

Low "smartness"		**High "smartness"**
Uncontrolled EV charging	Active control of charging, by shifting EV charging in time	Building/neighbourhood energy management incl. energy demand, production and storage
Passive control of charging, by encouraging EV owners	Load management of EV charging	Active use of stationary energy storage (batteries)
	Booking of charging services	Active use of bidirectional V2G solutions

Goals
Charging possibilities also with limited grid capacity
Efficient, practical, cost effective and reliable services for users
Enhanced grid stability and delay grid upgrades
Increasingly powered by local renewable energy sources
Empowering and engaging users
Energy efficient and climate-friendly
New business models and new companies
Secure, e.g. when it comes to fire safety and security of personal data

Table 2 Typical power use during EV charging, based on [11]

Type of charger	Voltage/Current	Power
Power plug for use in households	230 V/10 A/1-phase	2.3 kW
Households/commercial buildings	230 V/16 A/1-phase 230 V/32 A/1-phase 230 V/32 A/3-phase	3.6 kW 7 kW 12 kW
Semi fast chargers	400 V/32 A/3-phase	22 kW
Fast chargers (AC)	400 V/63 A/3-phase	43 kW
Fast chargers (DC)	500 V/>100 A	>50 kW

Examples of gross battery capacity of popular EVs in Norway are 24 or 30 kWh for Nissan Leaf, 24.2 or 35.8 kWh for Volkswagen e-Golf and 75–100 kWh for Tesla [12]. A typical charging profile for a single residential EV charging is shown in Fig. 1, from the project “Low Carbon London” [13]. The illustrated EV has gross battery capacity of 24 kWh. If using 6.6 kWh before recharging, it uses about 2.5 h at 3.7 kW when charging to full capacity.

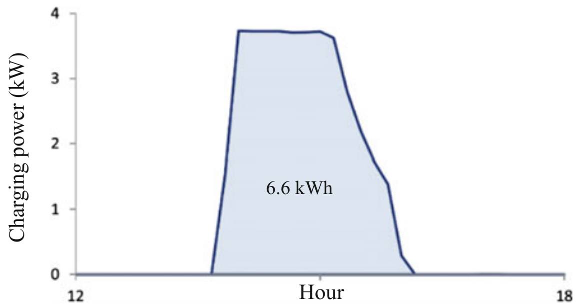

Fig. 1 Demand profile for a typical charging event, where the EV charges at 3.7 kW (i.e. 16 A) for about 2.5 h (charged to full capacity) [13]

Surveys of EV owners in Norway [14, 15] show that owners most frequently charge their vehicles at home or at work, relying on slow chargers. The third most frequent charging choice is publicly available slow chargers. The majority is charging during the night, probably at their home location, and there is also a peak during morning/mid-day, probably at their workplace. Fast charging is used to a little degree, and primarily as planned stops for long distance trips. However, this may be different for professional users of EVs, which was not investigated in detail in the surveys.

When comparing cars with different battery capacity, the charging patterns of owners with Nissan Leaf and Tesla differs. Compared to owners of Nissan Leaf, Tesla owners charge less during the day [15]. This indicates that car owners with larger battery capacity may mainly charge during the night. As the battery capacity of the EVs are increasing, one may therefore expect other EV charging profiles than today. If future EV owner are less anxious about having enough battery capacity for the evenings, even more EV owners may charge their car during the night time. However, this will also depend on other factors, such as convenience and costs.

2.2 *Interactions with Neighbourhood Energy System*

Beside management of the power demand of the EV charging station itself, it would be desirable if more advanced smart EV charging systems interact with the energy need in the buildings and neighbourhoods, the local energy production facilities and the capacity for local thermal and electrical energy storage.

Energy Need. Households typically have energy peaks in the morning and afternoon/evening, while non-residential buildings have peak loads during office hours [16].

Heating and domestic hot water (DHW) is a large share of the energy load in Norway, especially during the winter. Electricity is the main heating source for households, and accounted for about 73% of household heating in 2012 [17]. Many Norwegian buildings use heat pumps, including close to half of the detached houses [16]. The air-to-air heat pumps are most common. The high penetration of electric heating makes national electricity consumption very temperature dependent and high peak consumption can occur on cold winter days [18].

Some of the energy loads in a building or neighbourhood are flexible [18]. Flexible loads can be shifted in time, or regulated lower or higher. Heating loads and electric water boilers are often suitable for flexibility. Other electricity loads can also be flexible, such as the energy load of white goods, which can be shifted in time.

Energy Production. While there are several options for heating, solar cells (PV) is usually the most relevant energy technology for electricity production in a neighbourhood. PV systems generate electricity during the daytime, and mostly during the spring, summer and autumn. Usually, there are electricity demand in households and non-residential buildings during the day, which can be covered directly by PV. Still, PV systems cannot supply electricity in the evenings, when the demand usually remains high. A prosumer agreement exists in Norway, for locally produced electricity [19]. Smart meters (AMS) measure electricity export and import on an hourly basis. Financially, consumers normally receive less payment for electricity sold to the energy company than what they pay for buying electricity. This makes it beneficial to maximise self-consumption, i.e. minimising export of electricity to the grid.

Energy Storage. Both thermal energy storage and electrical energy storage can be utilized in an energy flexible neighbourhood. A DHW tank is an example of thermal energy storage capacity, which is often already available. If a DHW tank uses electricity as an energy source, this electricity use can be shifted in time or the load can be regulated. The project Linear in Belgium demonstrates how 2.4 kW DHW buffers of 200 litres can interact with EV charging [20]. The project found that the flexibility of DHW tanks remain more stable over time than the studied wet appliances. Further, the flexibility potential of DHW buffers and EVs is significantly higher than the flexibility potential of wet appliances.

In a building or neighbourhood, batteries are usually the most available technology for electricity storage. Beside stationary batteries, batteries in the EVs can be used in a V2G solution. The term V2G covers the solution were the battery in the EV delivers power back to the source. V2G takes advantage of the fact that private vehicles are parked on average around 93–96% of their lifetime [21]. In this configuration, the EVs can provide services like frequency and voltage regulation [22].

2.3 Smart EV Charging Systems to Improve Energy Flexibility

A smart EV charging system can be part of an energy management system, which improves energy flexibility of a building and a neighbourhood. Figure 2 illustrates scenarios for a neighbourhood with and without EV charging and energy management. The figure is developed as an example, with input from hourly electricity consumption and production data from a ZEN pilot area.

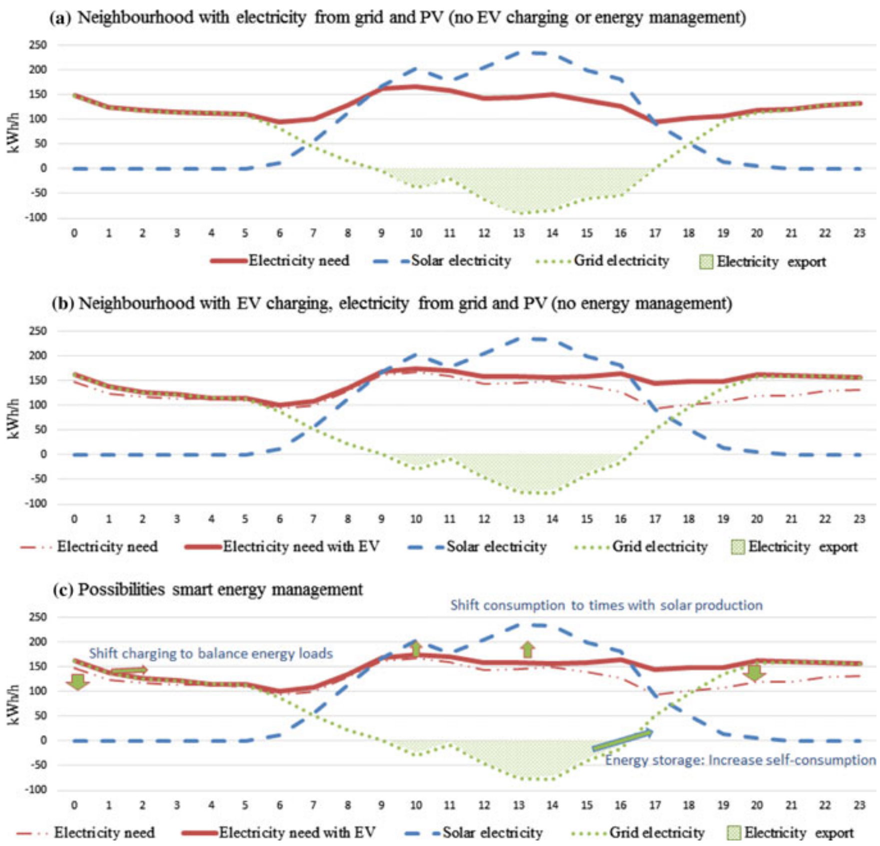

Fig. 2 Daily energy profiles for a neighbourhood without and with smart EV charging, with hourly electricity need, grid electricity, solar electricity, EV charging and battery use

The ZEN pilot area is a university campus with in total around 10,000 m^2 heated area. The electricity consumption data is from a Monday during springtime (May 30, 2016). The electricity production data is from the year after (May 30, 2017), but is up-scaled with a factor of four. After the up-scaling, the illustrated PV plant represents 280 kW_p installed power. The EV charging data is based on [23], with charging measurements from an EV pool in Trondheim (230 V, 16 A). The charging data is up-scaled with a factor of two, illustrating a situation with 30 charging outlets for EVs. In average, each charging outlet provides 15 kWh during the illustrated 24 h.

Three different example scenarios are illustrated. Figure 2a represents a neighbourhood with no EV charging or energy management. Electricity is provided by the grid and PV. Since this is a university campus, the peaks in demand matches quite well with the solar energy production; Better than what could be expected in a neighbourhood with households only. During mid-day, electricity is exported to the grid. Figure 2b represents the same neighbourhood, but with EV charging. The energy need for EVs especially increases the energy consumption in the afternoon. Scenario 2c illustrates possibilities with smart energy management. Energy loads can be shifted from the evening and early night, to reduce the energy peaks. This can be done by delaying EV charging to the night-time, and also by moving other energy loads—such as electricity to the thermal storage tank. More EVs can be charged during daytime, when there is solar electricity available. If also batteries are used in the system, solar electricity can be used in the evenings. With such an energy management system, less electricity is exported and the maximum grid loads are reduced.

2.4 Examples of Commercial Smart EV Charging Systems

Vulkan Garage in Oslo. The charging station Vulkan has the possibility of charging 100 EVs simultaneously. The system is partly financed by the EU project SEEV4-City and is implemented by Aspelin Ramm, Oslo municipality and Fortum. The partners are testing new business models, combining services for residents and professional users. Charging of 3.6 kW power is free during night-time. During daytime, dynamic charging services are available for a fee. Power from 3.6 to 22 kW is available at the charging points, which are managed individually. A battery package of 50 kWh is installed in the garage, as a buffer and to manage peak loads. The garage is prepared for V2G solutions and the next generation fast chargers of 150 kW [24, 25].

Apartment buildings in Norway. The company Zaptec has developed a solution for apartment buildings with limited grid capacity, sharing the power dynamically across several charging stations. Balancing technology makes it possible to charge over 100 EVs in 24 h, on a single 63A circuit. Up to 22 kW of power is available on every charging station. The chargers communicate through a cloud solution.

Frederiksberg Forsyning in Denmark. Ten Nissan eNV200 cars and ten Enel V2G charger stations are located at the headquarters of Frederiksberg Forsyning in Copenhagen [26]. California-based Nuvve provides a platform that controls the power flow to and from the cars. When the EVs are not in use, they can be plugged into the charger stations, receiving energy from and providing energy back to the national grid. The total capacity made available by the ten chargers amounts to about 100 kW.

3 Discussion

With the increased use of EV charging, it is important to investigate if and how smart EV charging systems can improve the energy flexibility of an area. Different situations, e.g. an apartment building, a neighbourhood or a fast charging station, will have different challenges, possibilities and goals, which will require different solutions.

For example, for an apartment building with an old grid, the main goal may be to provide charging possibilities for the residents, even though there is limited grid capacity. Load sharing between the charging stations may solve the issue, or it may be an advantage to also control some of the energy flexible loads in the building or to maximise self-consumption of electricity from PV. For a neighbourhood, the aim might be to avoid grid upgrades in the area. In cooperation with the grid company, energy flexible solutions in the neighbourhood can play an active role in the energy system. A smart EV charging station may play a role as a hub in the neighbourhood energy management system. For a fast charging station, the aim may be to reduce the costs for energy loads, by introducing a battery to the system.

Both in single buildings and in neighbourhoods, there are potential for interaction with heating loads and HVAC facilities. DHW tanks are an example of a flexible load, which can be realized within the comfort requirements of the user [20].

Batteries in the vehicles will most likely play a role in future smart charging systems, though V2G solutions. This is a new technology solution which can provide new opportunities for energy management and participation in the electricity market.

If consumers are energy flexible, this has a value for the grid companies [27]. With the introduction of smart meters (AMS), it is possible to introduce market mechanisms to increase the use of energy flexibility—as an economically attractive alternative to grid investments. As in several other EU countries, the introduction of new market mechanisms for flexibility are investigated in Norway [28]. Such a mechanism, may facilitate for building owners and neighbourhoods to play a more active role in the energy system, together with the grid company.

Piloting of new technologies and solutions will provide more knowledge about smart EV charging systems. Such solutions may therefore be installed in the pilot areas of the ZEN Centre, to better match the energy loads in buildings and infrastructure, with local electricity generation and thermal and electrical energy storage.

4 Conclusion

Increased use of EVs calls for new and innovative solutions for charging infrastructure. At the same time, it is desirable to better match the energy need in buildings and infrastructure, with energy generation and energy storage in a neighbourhood.

This study is a first step towards answering three research questions: (1) How does the energy need for EV charging and charging profiles fit with the energy need and energy production in a neighbourhood? (2) How can a Smart EV Charging System be part of an energy management system which improves energy flexibility of a building and a neighbourhood? (3) Which goals and technologies demonstrated in smart EV charging systems today, can be relevant for the ZEN pilot areas?

If energy management solutions are integrated in smart EV charging systems, such systems can improve the energy flexibility of a neighbourhood. Literature and commercial EV charging systems provide examples of smart EV charging systems, which e.g. provide dynamic load management, offer a variety of charging services and demonstrates V2G solutions. Such smart EV charging systems can also interact with heating loads and HVAC facilities in a neighbourhood.

Smart EV charging systems can play a role in the pilot areas of the ZEN Centre. Piloting of new technologies and solutions will provide more knowledge about how charging systems can play a role in the neighbourhood energy management system.

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