Deliverable D4.3 – B1

Grid Impact studies of electric vehicles

Parameters for Assessment of EVs Impact on Low Voltage Grid

Prepared by:

Charlotte Karlshøj Madsen
Fannar Örn Thordarson
Jan Rasmussen
Danish Energy Association

Date: **November 25th, 2013**

Version: **1.5**

Document Information

Authors

	Name	Company
Key authors	Charlotte Karlshøj Madsen	Danish Energy Association
	Fannar Örn Thordarson	Danish Energy Association
	Jan Rasmussen	Danish Energy Association

Distribution

Dissemination level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Revision history

Version	Date	Author	Description
1.0	August 3rd 2012	Charlotte Karlshøj Madsen	Draft
1.1	September 21st 2012	Charlotte Karlshøj Madsen	Draft
1.2	March 29th 2013	Jan Rasmussen	Submission for external review
1.3	July 19th 2013	Jan Rasmussen	Submission for external review II
1.4	September 21st 2013	Jan Rasmussen	Submission for EC review
1.5	November 25th 2013	Jan Rasmussen	Submission

Status

Status	
For Information	
Draft Version	
Final Version (Internal document)	
Submission for Approval (deliverable)	x
Final Version (deliverable, approved on)	

Table of Contents

List of Figures

List of Tables

1 Executive summary

The objective of this report is to describe parameters relevant for performing a comprehensive assessment of EV's impact on the low voltage electricity grid. The report serves as basis for the following D4.3 reports as described in 2.1.1 related to grid impact on low voltage grids. However the report can be used as introduction for external stakeholders, who wish to improve knowledge on EV's impact on the low voltage electricity grid.

The identification of the parameters is based on the response of several DSOs on a survey regarding assessment of EVs together with knowhow gained in previous R&D projects related to EVs, such as EDISON, G4V and MERGE.

The following parameters of importance have been identified, through studies of previous R&D projects such as EDISON, MERGE and G4V and interaction with a number of DSOs. An overview of the parameters with a description and their relations to the grid can be found in Appendix 1

	Parameter
EV	Number of EVs, N_{ev}
	Battery type or size B
	Converter C_{ev}
Charging	Charging power S_{ch}
	Charging time T_{ch}
	Charging profile CP
	Energy Consumption E_{ev}
Charge Management	Charge Management Strategy CMS
	Charger intelligence CI/CAI
	Fast Charger
	Price of electricity
Grid parame-	Consumption S_c
	Production S_p
	Grid Topology
	Capacity

The charging profiles are subject to some degree of uncertainty, especially when assessing EVs' impact on local low voltage grids, e.g. at a residential level. Thus a stochastic method has been used to derive charging profiles to assess EV's impact on local low voltage grids, which includes the uncertainties. The method is described in Annex 2.

2 Introduction

Europe is undergoing a change from fossil based energy consumption to renewable energy sources such as wind, water, solar energy, burning of waste and bio products. A great part of this development has been in the electric market, exchanging the known power production units to something more environment friendly, thus reducing CO2 emission and lowering the dependency on heavy fuel oil products (HFO). For a likewise exchange in the transportation section, the electric vehicles have long been in use as trams and trains. To fulfill the Transport 2050[1] which states a drastic reduction of CO2-emission from the transport section, new technology is needed and for the common car the electric car is moving in.

2.1 *Electric Vehicles for personal transportation*

The exchange from oil based cars to electric cars (EVs) will have a significant and positive effect on the society, the local environment in particular, and set new demands to the electric grid.

To supply the necessary background for the interaction of the EV parameters, and their influence on planning and operation of the low voltage grid, several topics are outlined in the following.

2.1.1 The Green eMotion Project and D4.3

The EU project Green eMotion (GeM) focus on electric vehicles; the technical development, penetration, and the interaction with society. The GeM consists of eleven work packages investigating numerous subjects related to EVs. The project is supported by partners widely covering the European continent and each investigation stands as a small part of a larger picture.

D4.3 will include recommendations for future planning tools for DSOs and an investigation of the effect EVs have on the grid and power quality. D4.3 consists of several

---

[1] A goal for the future in the transportation section, details can be seen for an example at: http://europa.eu/rapid/pressReleasesAction.do?reference=IP/11/372&format=HTML&

reports covering different topics relating EVs to the electrical grid. An overview of D4.3 is shown in Figure 2.1.1.

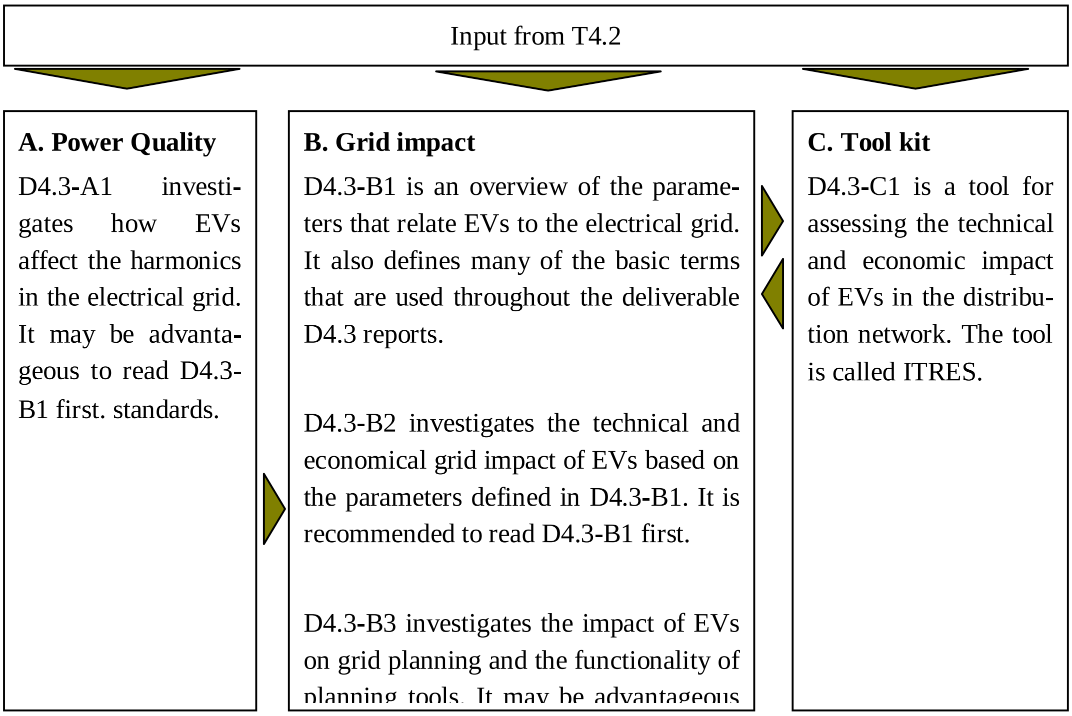

Figure 2.1.1: Overview of deliverable D4.3.

All reports are available on the Green Emotion website under following link:

http://www.greenemotion-project.eu/dissemination/deliverables-infrastructure-solutions.php

2.1.2 The subject for the Investigation

In the following, the subject of parameters which relate the electric vehicle to the local grid will be the main topic of this report. The purpose is to identify and describe the important parameters and their impact, in order to explore the future of the grid for low voltage levels.

As the consumption of electricity grows and the energy usage in the transport section slowly shifts to electric energy consumption, new challenges will meet the grid at low voltage levels. For the task T4.3 the main deliverance is the effect that EVs will have on the grid concerning planning for the future. This includes the reinforcement costs for expansion of grid capacity, investments in supervision, and concept for a better exploitation of the established grid.

This investigation is the first step and seeks to include all parameters with importance now and in the immediate future, based on previous RD&D projects and input from gridplanners. The investigation includes:

- A description of most important properties of the involved technology for EV, charger, and electric grid.
- A definition of the parameters which are of importance for the interface between EVs and the electric grid.
- The parameters' predicted development as EV penetration rises with focus on challenges.
- Mitigation measures which could take action towards minimizing the negative impact.

2.2 Outline of this report

In this introduction the Green eMotion project has been described underlining the aspects of this investigation and their relation to the entirety. The introduction chapter ends with the terminology in use in this report, including a table as common source of abbreviations, to aid the reading process.

Next chapter is the technological background for understanding the parameters and covers both the EV, the charging procedure and the electric grid. In chapter 4: "Parameters which Relate the Grid and the EV" the parameters of interest are described and the relation and impact of their variations are interpreted to display the complexity of these considerations.

Finally, a chapter which regards to the future of the grid and the planning it requires when seen from the grid companies considerations. To include the grid company (DSO) angle in the planning perspective, a survey has been done for a base in the planner's challenges.

The following appendix includes a parameter table which in short gives a map of the parameters considered (Annex 1) and a simulation study for the impact of the EV charging on the low voltage grid (Annex 2). For information, the template used for the survey is included in the appendix (Annex 3)

2.2.1 Terms and Abbreviations

The commonly used abbreviations and terms are shortly described here. Since the project is European all terms relate to the general European standards.

Abbreviation	Representation	Explanation
AMR	Automatic Meter Reading	A modern electricity meter, typically at the consumer, with measurements of consumption per hour or day which logs and remotely sends the data to the vendor.
BMS	Battery Management System	An integrated software and circuit board in the EV which manages the charging process and sends information to the driver display.
ICE	Combustion Engine Cars	The ordinary car with internal combustion engine, often used as an opposite to EV.
CHP	Combined Heat and Power	Power plant in a range of sizes which produce both electricity and heat.
DSO	Distribution System Operator, grid owners	The company which owns the lower voltage level grids. The company can be private, owned by state or a mix.
EV	Electric Vehicle	Electric car which recharges it's battery from the grid. Substitute for and ordinary commute of family car, not a truck or a train.
EVSE	Electric Vehicle Supply Equipment	The charger or charger stand, including cables and electronics for communication.
EVSE Op.	Electric Vehicle Supply Equipment Operator	The company which operates the Electric Vehicle Supply Equipment, also known as the Infrastructure Operator.
EVSP	Electric Vehicle Service Provider	Supply services to the EV owner, e.g. charging at fixed prices.
HFO	Heavy Fuel Oil	Products and fuel based on crude oil from e.g. drillings at sea. "HFO based car" thus means a car that used gas or diesel as fuel.
OHL	Overhead line	An electric line typically high-voltage, which is carrier through the air high up in towers. The lines are air insulated and thus thinner than cables.
PCC	Point of Common Connection	In general the place in a grid where a specific component is connected.

PQ	Power Quality	Describes the quality of a grid or in a point of the grid, by use of several parameters which may be measured or calculated.
TSO	Transmission System Operator, transmission grid owners	The company which owns and operate transmission grid. Typically, this includes the high(er) level(s) of grid and ownership by the State, possibly partly.
WTG	Wind turbine generator	A power plant generating power based on wind, either a wind turbine or a wind farm.

Table 2.2.1 Abbreviations of importance.

3 Technological Background

The parameters between EVs and electric grid are intertwined and based upon grid parameters such as local voltage, the transmittable current, and the general capacity of the grid. Furthermore, the technology in the EV, the EV charger, the behavior of the user, and the charging profile will also be parameters of importance.

All of these parameters and more are covered in the next chapter, and the background for understanding the parameter's influence is provided in the following.

First a short review of the content of an EV and the basics of charging. Last an explanation of fundamental grid structure, the voltage levels, and general behavior when events occur in smaller low voltage grids.

For an outline of the impact on grid, future and planning, see chapter 5.

3.1 Electric Vehicles

The electric vehicles are in this investigation meant as an alternative private vehicle to the common family or commuter car, i.e. not a train or tram. Thus an EV represents a car in which the primary propulsion is from an electric motor and not i.e. an internal combustion engine car (ICE). This means that the fuel will not be HFO products but electric energy delivered by a rechargeable battery. This energy is provided by the electric grid at ordinary consumption voltage, typically 0.4kV line or 230V, see section 3.2 for details. Away from home, high power DC charging, through an off-board rectifier, is an option to extend the range of EVs, however the AC power mentioned in this above is what EV owners have access to at home.

3.1.1 Benefits in society

The society will benefit from fewer oil based vehicles in the streets; particularly in the cities reducing the oil based cars will reduce CO2 emission, fewer dangerous particles in the air, and a reduction in noise etc. The EV is an excellent replacement for a city car, however, the process depends on the user and this means that user-friendliness is paramount for the shift in paradigm. Another possibility is actions from government, since elements such as the electric infrastructure and the condition of a country's car fleet is on the political agenda.

3.1.2 The Technology in an EV

The state of technology currently has limitations for the size of the battery and drawbacks such as expensive production, large element size, and heavy batteries. This means the EV has a slow penetration rate due to high expenses and inconveniences for the user such as the shorter range per recharge. However, the technology is fast maturing and the infrastructure growing for a higher level of user friendliness. The focus here is a likewise level of grid friendliness and an optimum interface, see further regarding parameters in Chapter 4. The following describes the most important contents of the EV which sets it apart from other cars. These elements in connection with the grid PCC is graphically presented in Figure 3.1.1 for an easy overview of the important EV and charging elements.

3.1.2.1 The battery for energy storage

The electric car has an electric motor which provides the thrust for driving. The energy is stored in a battery of a given size which limits the amount of stored energy. For a typical EV[2] this could be 24kWh = 56.4 MJ which is the maximum energy for fuel per recharge. Since the battery is direct current electricity (DC) it cannot directly connect to the grid.

3.1.2.2 A converter connects the battery to the grid

The AC/DC converter is the electrical link between the grid and the battery in the EV. The converter is set up to intake a certain type of electricity, typically AC single phase 230V max. 16A. The connection can be a simple cable connecting to the socket, as in Figure 3.1.2 mode 1. This signifies the charging is determined by the control log or BMS integrated in the EV which is a static setting. Further, no control or change in the charging process is possible; see the following Chapter 4 for details.

[2] Nissan Leaf, http://www.nissan.co.uk/#vehicles/electric-vehicles/electric-leaf/leaf/pricing-and-specifications/specifications or Renault Fluence Z.E. at 22kWh http://www.renault.com/en/vehicules/renault/pages/fluence-ze.aspx

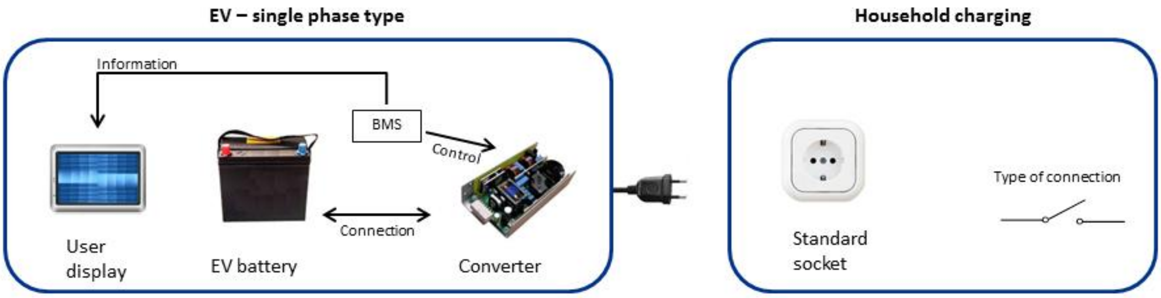

Figure 3.1.1 The battery, converter, BMS and user display in an EV with a connection to a domestic electric socket with an ordinary PCC at e.g. 230V and 10A.This setup falls in charging mode 1.

3.1.2.3 First level of control for the charge: BMS

The Battery Management System is the first layer of software in front of the battery. Its data are the specifications of the battery; how much current it may absorb and how depleted the battery is. The BMS is integrated with the converter to protect the battery since the component is crucial for the EV's usefulness and value.

3.1.2.4 User information on display or remotely

The electronics in an EV include software to inform the user on the display inside. Like the gasoline gauge in HFO cars, the level of energy remaining is important information for the driver, though direct display the battery's remaining MJ level seems rather pointless. The software may provide parameters for the user such as; estimated distance remaining with the current use and resources, estimated time of charge when connected for regaining a full battery, estimated range if ending charge now or perhaps in ten minutes. If the CPU include data input from a GPS chip and web protocol the software may enable further information to the user or other stakeholders by use of applications on cell phones and the like.

The interactions and properties of each element may vary according to charging mode and setup, which is a complex matter. In Figure 3.1.1 the elements of the EV is shown and the simplest connection to the grid. The next section describes further the variation in setup and some of the impact on the user.

3.1.3 The charging process and management

In order to charge the EV battery, the supply equipment (EVSE) i.e. the charger with integrated hardware and software, on both charger stands and household chargers must be compatible with the EV. Since EVs are produced in various types, the setup of charging vary as well but can be sorted in a number of modes, described in IEC61851-1 and depicted in Figure 3.1.2.

The charging process itself depends on technical and electrical properties, which are all described in the chapter regarding parameters, Chapter 4, but the basics of EV charging seen from the user's perspective is perfunctory described in the following.

3.1.3.1 Different modes for charging

- Mode 1 charges from a domestic or industrial socket with the BMS system in the EV in control. The maximum limits are 250/480 V and 16 A.
- Mode 2 has a special cable with an in-cable control box that can send its (static) data to the EV for communication with BMS. The connection is to a standard domestic or industrial socket with limits of 250/480 V and 32 A.
- Mode 3 requires a connection with an integrated communication cable since the control pilot function in the charger needs to communicate with the BMS in the car. The charger may contain a CPU and to manage the charging procedure. The connection is a dedicated EV socket with 230/400 V. The current limit may vary but are often 32A.
- Mode 4 is a DC setup for the EVs which have this function. The level of communication may vary but the control pilot function extends to the equipment in the charger. The limitations for voltage and current will be defined in the upcoming standard IEC 61851-23.

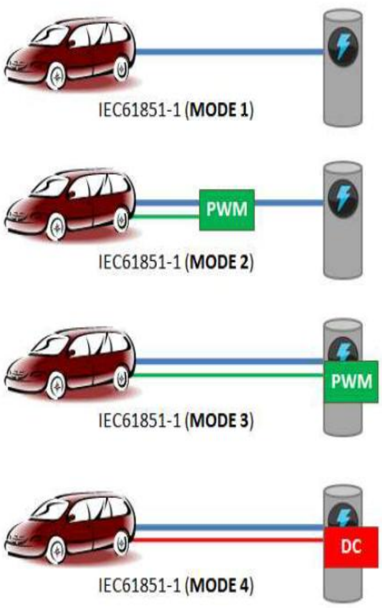

Figure 3.1.2 The 4 different modes of charging according to IEC61851-1

3.1.3.2 The impact of charging modes

In general, the communication between charger and EV, and the surroundings and charger, are of profound importance, as described in detail in Section 4.1.3 regarding charge management and strategies. When the amount of EVs rises it is foreseen that management of the charging becomes necessary, if high levels of user and grid friendliness is wanted. A further description of charge management, charging strategies, and their properties is stated in Chapter 4; Parameters which Relate the Grid and the EV.

In the following a small calculation will indicate the general parameters for the charging process which will have a critical influence on the availability of the EV and thus the experience for the user.

3.1.3.3 The maximum charging power available from the grid

When the EV and the EVSE have reached an agreement, the charging progress begins. In simplified terms, the charging power P_{ch} will rise to a maximum level and continue until the battery is fully charged. Among others, there is a maximum level of current depending on the outtake and a certain level of voltage available from the grid. If the grid is a standard 230V on a limited phase current i.e. 10A the charging power P_{ch} becomes:

$$U_1 I_{st} = P_{ch} \quad \Longrightarrow \quad 230V\ 10A = 2.30\ kW\ (\cos(\varphi) = 1)$$

In cases where the maximum charging power of the EV exceeds the power available from the grid, precautions must be taken.

3.1.3.4 The time frame for charging depends on charging current

Observing a 24 kWh battery, which is a commonly used battery size, e.g. in Nissan Leaf, charged with 10 A at 230V. The charging time T_{ch}, disregarding the limitations at very low and very high SOCs, becomes:

$$\frac{24kWh}{2.3kW} = 10.4\ h$$

This is the extent of an entire evening and night. If both the EV converter and the grid in the area can handle a larger current, then the charging power can be raised to 3.7kW at 16A. If the EV battery is in general between 50% and 75% depleted the charging time then becomes:

$$75\% \frac{24kWh}{230V\ 16A} = 4{,}89h$$

$$50\% \frac{24kWh}{230V\ 16A} = 3{,}26h$$

These correspond 4 hours and 55 minutes and 3 hours and 15 minutes respectively. This small example shows how several parameters influence the charging process of the EV. So far, voltage level, allowable charge current, the maximum charging power, and the energy demand based on size and usage of the EV battery are all parameters used to calculate a time frame for the charge; a full picture means more parameters and a more complex correlation.

In order to fit the charging into a night or a workday, the charging current was raised to 16A, providing the user with a shorter charging time and more options. However, raising the current to what in some households would be the maximum level could pose a challenge for the electric network in an area, because what happens when all the neighbors return from job with their EV and charge at the same time?

3.2 The system of Electric Grids

The purpose of the electrical infrastructure is to provide electricity to businesses, households, and the industry everywhere in the country while providing a sound base – the network – for electricity producers and vendors to supply, buy and sell electricity. Since most businesses would come to a halt if the supply of electricity fails, the government regulations seek to enable a stable and safe grid for all stakeholders.

This means that electricity is on both the political and the private agenda and affects all private persons and businesses in a country. With high investment costs and a rising dependency on energy supply from electricity, the future of the grid is of particular interest. This is discussed further in Chapter 5.

The grid being an important asset in itself means that the owner companies are often partly State owned or tightly governed. In Denmark the top layers (transmission) are owned by Energinet.dk which is a State company. The distribution levels (50kV and below) are owned by approx. 75 distribution system operator companies (DSOs) in the private sector.

In the following the general structure of electric grids in Europe is described, with the Danish grid as example. The layers of transmission grid, distribution grid, and residential grid are described and highlights given to indicate why the EVs pose such a challenge.

3.2.1 The structure and basis of electric system

The entire electrical network is based upon a system of AC grids with various voltage levels, connected by transformers to step up or down the voltage. Different levels have various benefits and the high voltage is used for transmission of electric energy to reduce losses. High voltages are typically above 110kV and extra high above 220kV. For a simple graphical overview which shows an example of production and consumption in various voltage levels, see Figure 3.2.1.

Below and down to around 50kV the grids are called sub transmission or regional transmission. Established grids in Denmark have the levels 60/50kV, 10 and 0,4kV called the distribution grids with 0,4kV being the ordinary consumer level.

Since the system was built to move large amounts of energy to population areas with no production, newer units such as small-scale CHPs, WTGs, and micro solar cells have changed the service the grid should provide.

Since the potential amount of consumers may be as high as 23-30% of a country's population, the penetration of EVs in the transportation sector will have an immense impact on the electric grid as well.

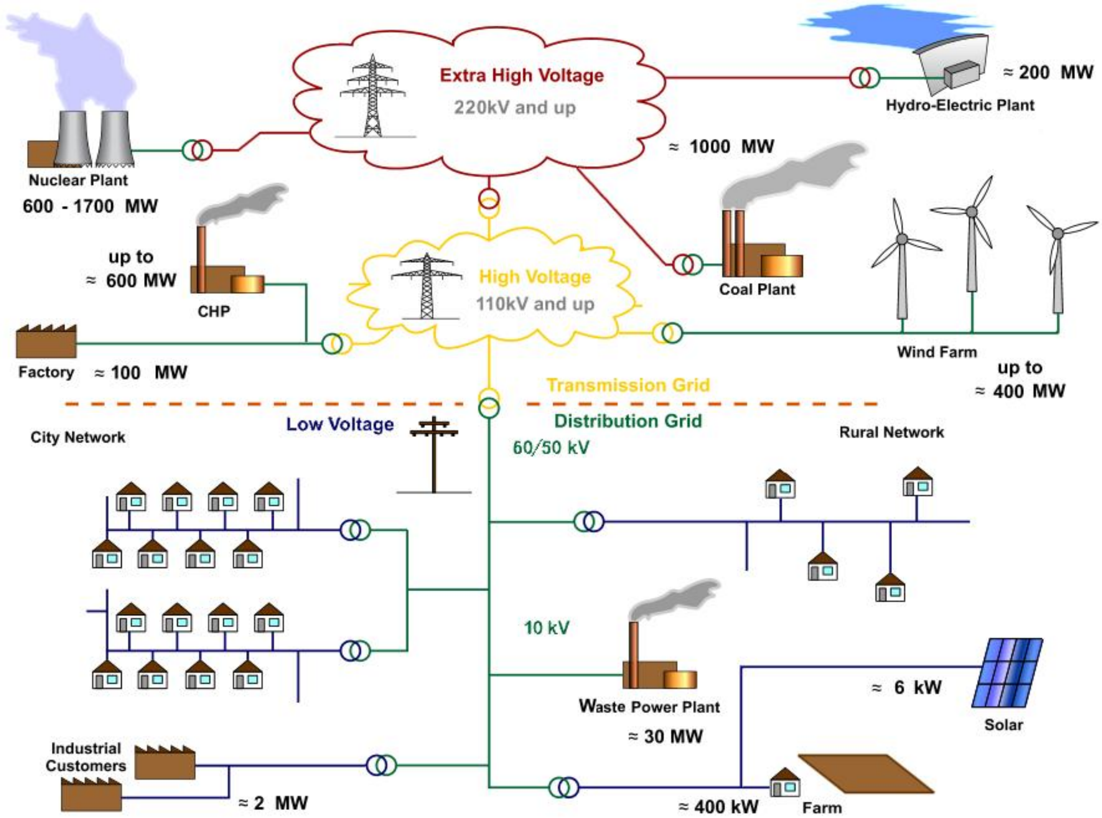

Figure 3.2.1 An overview of the voltage layers (DK) and the general connection levels for various units. The low and medium voltage levels contain the consumers and small scale production while the high voltage grids connect to a variation of production units and particular demanding consumers.

3.2.2 The high Voltage Grids

3.2.2.1 Transmission grids are the electric highways

Transmission grids with high voltages at e.g. 400kV are for large production units and long distance transmission. A transmission line can stretch across a country or a border like the three phase 400kV AC double connection between Denmark and Sweden. This is done via sea cables but often the high level grids are OHL based since they are cheaper, easier to establish and more robust in case of overload.

The interconnection also means that the grids in different regions must stay in sync and support the voltage, frequency, etc. in unison. This is not true if the connection is a HVDC cable, as the connection between DK and Germany. A single connection such as DK-SW will represent a bottle neck but in closer regions the sub transmission levels, 220, 150 or 132 kV will add their capacity for a larger flow. Adding the two transmission layers, the topology is often circular or mesh and the lines are often double to provide a backup in case of failure on one set. All this to provide several opportunities to support the lower levels.

The top level grids contains more than lines for transmitting energy, a variety of elements are connected to provide voltage stability, reactive power, protection against overload or lightning etc. This adds to the reasons for why a high level of supervision and measurements are common; to provide knowledge to the TSO and DSOs. Fast or large scale production such as nuclear, water, and the coal power plants produce to these levels, and particular demanding consumers e.g. a factory may be connected in (sub) transmission, see Figure 3.2.1 for an example of structure.

3.2.2.2 The distribution grids are the main roads

The distribution grid lies below transmission grid and is connected by an amount of transformers to the higher level grids. As with main roads they cover most of the country but the highway routes are broader.

These levels usually contain the multitude of medium production units; CHP, WTG, and power plants. However, the larger units will often step up to high voltage immediately and feed the transmission grid to supply areas with high consumption and low production.

Traditionally, the lower levels have a branch structure with a single feed-in transformer that provides an area of 10kV for industrial consumers and radials of household consumers at 0.4kV. The level of supervision is low since the number of elements is vast and the last voltage and current measurements may be e.g. at the secondary side of a 50/10 kV transformer.

Figure 3.2.2 shows how the transmission grid at 400kV (in red) provides the long double lines for the "highway" of the electric grid. Below is the sub transmission grid at 132kV (in yellow) with a mesh structure. Double lines do exist to supports e.g. a distant area. The distribution grid or "main roads" (50kV in light green and 10kV in dark) has a general linear structure with slight reinforcements. The residential grid at 230V in blue is constructed by radials and the isolated ends show where it is common to have single phase. The simple graphics show the strong mesh structure of transmission grid compared to more linear structure of distribution grid. The residential grid is widespread to reach every corner of the country.

3.2.3 The low Voltage residential grid for consumers

If the above levels were highways and main roads, then the residential grid was originally built as one-way streets. The voltage level for residential grid is typically 230V from a phase to the neutral phase, also denoted 0.4kV which is the phase-to-phase (line) voltage between two phases, only available were several phases are connected. In most regions of EU the power is single phase at residential consumers but in Denmark, Sweden and parts of Germany the three phases are carried all the way through.

Almost every consumer is placed at residential grid level, and a vast number of components, making a general supervision virtually impossible. For account purpose the *consumption* (kWh) for each consumer is measured and can be accumulated e.g. per radial. In city areas the grid furthermore consists mostly of cables and has a high density of users, a high level of reinforcement costs, and is likely to first reach a high EV penetration rate.

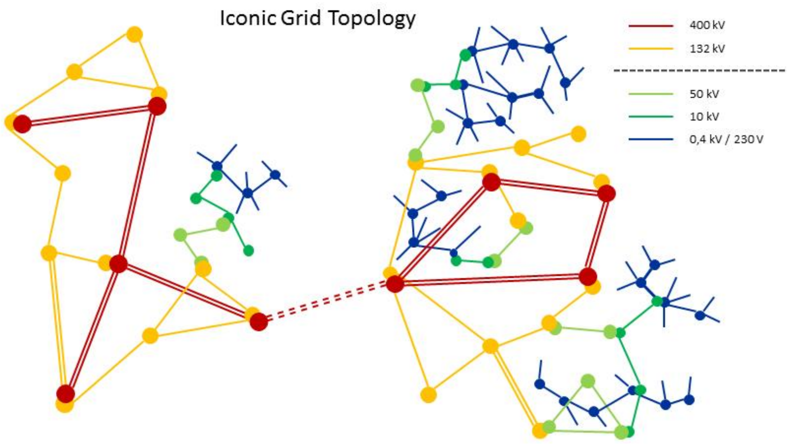

Figure 3.2.2 An iconic overview of the electric system with levels set as in Eastern Denmark. The dashed line is DC which separates the AC areas. Transmission grid has a mesh structure while distribution grid has a radial structure.

3.2.3.1 EV's load behavior in low voltage grids

An ordinary Danish household may vary in consumption: from 0.8 kWh/h (as low as 0.1 at night on a summer's night) to 3.7 kWh/h (up to 5 in winter's peak time). If the EV charges at maximum current 16A single phase, the consumption of 3.7kWh/h will represent from 100% to 460% extra load in the household. This significantly changes the use of the residential grid, which already is under pressure from micro VE, heat pumps etc.

The two main concerns are due to the place of PCC; at low voltage the grid is not as *strong* i.e. the amount of load may exceed the grid properties. If every consumer on a radial (every house on the same road) acquires an EV, the accumulated current from the transformer may *overload* both transformer and the connected cables. At the end of a radial, the last EV on the line may receive a significant *lower voltage* than the first, since voltage decreases from the transformer to the end and drops for each connected load. This pull from the 230V radial will affect the next level and possible other radials, which may cause electric problems in a wide area.

Other concerns involve the *sturdiness* of the low voltage grid i.e. how easy the grids begin to flex. The grid must be elastic but there are limitations to its flexibility, and the EVs cause deviations in current and voltage which may lead to fluctuations; locally some fluctuation is acceptable but if it spreads to a wide grid area, radials on both 10 and 0.4 kV may be in a fragile state moving towards failure. The supervision will not reflect this unless it reaches a measure point e.g. at 50/10 kV grid interface which means the grids at the two lowest voltage levels may undetected have a poor PQ and a fragile operational state.

The combination of lack of particular knowledge, a significant change in consumption pattern, and particular areas at risk for overload is a challenge for the low voltage grid and the DSOs who manage and maintain them. Solutions for the grid of tomorrow are needed, but in order to develop a well based solution, the problem must first be investigated. In the following this is done by defining and investigating parameters: Which parameters link the EV and the grid, which are important in terms of impact, and which can be eliminated with mitigation measures.

Country	Current level in residential Grid
Denmark	3 phase to all residents, AC 400/230 V Current per phase 10-16 A PCC 25A per phase, 3 phases
France	1 phase to all residents, AC 230 V Current per phase 10-16 A PCC 60 A per phase, 1 phase
Germany	3 phase to most residents, AC 400/230 V Current per phase 10-16 A PCC 63 A per phase, 3 phases
Great Britain	1 phase to residents, AC 230 V Current per phase 10-32 A PCC 60 A per phase, 3 phases
Italy	1 phase to residents, AC 230 V Current per phase 12-16 A PCC up to 63 A per phase, 1 phase
Spain	3 phases to buildings, 1 phase at households, AC 400/230 V Current per phase 10-64 A, typical 16 A at residents PCC up to 75 A per phase, 3 phases available

Table 3.2.1 Grid parameter values for selected European countries

3.2.3.2 Reference to previous RD&D projects

A number of different parameters related to EVs impact on the low voltage grid have been investigated across Europe within different Research, Development and Demonstration projects e.g. G4V, MERGE and EDISON. Parameters such as charging profile, power quality, grid topology and capacity have commonly been investigated in those projects. Below is listed the most relevant documents from the mentioned projects related to EVs impact on the grid.

G4V

- D5.1 Modeling of the energy demand related to the mass introduction of EV/PHEV
- D6.1 Impacts of EV on Power Systems and minimal control solutions to mitigate these
- D 6.2 Estimation of Innovative Operational Processes and Grid Management for the Integration of EV

MERGE

- D2.2 FUNCTIONAL SPECIFICATION FOR TOOLS TO ASSESS STEADY STATE AND DYNAMIC BEHAVIOUR IMPACTS, IMPACT ON ELECTRICITY MARKETS AND IMPACT OF HIGH PENETRATION OF EV ON THE RESERVE LEVELS
- D2.3 POWER QUALITY ASSESSMENT
- D2.4 FUNCTIONAL SPECIFICATION FOR ESTIMATING ADDITIONAL INVESTMENTS IN DISTRIBUTION NETWORKS WITH HIGH PENETRATION OF ELECTRIC VEHICLES
- D4.1 RECOMMENDATIONS REGARDING THE BEST PLANNING PRACTICES COMBINED WITH THE MOST EFFICIENT STRATEGIES FOR CHARGING EV TO BE FOLLOWED BY THE DSO

EDISON

- WP2.2 Potential Analysis for Electric Vehicles Grid Integration
- WP2.4-6 EV Portfolio Management and Grid Impact Study
- WP2.7 Grid Codes and Regulation related to EVs

Parameters investigated in the above have, together with other parameters, been included in the list of parameters required to make a comprehensive assessment of EVs impact on the low voltage grid.

4 Parameters which Relate the Grid and the EV

In order to investigate the effect EVs have in the grid, a discussion must include a common ground of understanding. When using a term or discussing a concept, the terminology in use must be aligned in order to obtain a good result and understanding of the topic. When looking into the interface of grid and EV this includes some complex interaction and concepts which have been described in the earlier chapters.

To further investigate and enable a detailed discussing, this interface has been defined by *parameters* which will be described and defined in this chapter. To include as many relevant parameters as possible, an open debate and brain storming has been performed, previous studies has been analyzed and a survey aiming at DSOs has been created. The debate seeks to include and define those parameters which will or may have an effect, and for each determine: Which aspect the parameter covers, which elements the parameter depends on, which impacts it has on the grid and any important correlation (dependency, effect, or synergy) the parameter is seen to have with other parameters.

Since some parameters are technical this definition and correlation is soundly based, but for parameters which include future aspects or expected correlation, the definition becomes complex. The purpose is to clarify the interface for a further discussion on grid effects and planning in the next chapter, but also take the comprehension of the challenges a step forward, since this is required for the following investigation; for finding solutions to the challenges discovered.

In Annex 1 the parameters are summarized in a table for a convenient overview.

4.1 Description and definition of parameters

4.1.1 Parameters derived from EV

Name of parameter	Description
Number of EVs N_{ev}	The number of EV's either on a radial, in a grid or in a country
Battery size B_{ev} [kWh] or [MJ]	The battery described as size or capacity. The maximum amount of energy which the battery can absorb from the grid assuming the battery is discharged when charging begins.

Converter C_{ev}	The converter which connects the AC grid to the DC battery. Will also in general include the CPU and software incl. BMS which manage the charging procedure.

Table 4.1.1 Parameters derived from EV

Number of EVs

The parameter number of EVs describes the amount of EVs connected to a particular area; a grid or a country. The EV will then be an extra consumer or add its demand to a consumer already established.

Dependency: The amount of EVs, and their type and placement are all user depended factors, and will be affected mainly by sociological factors such as: the costs for EVs versus HFO cars, the cost of fuel, and legislation.

Grid impact: A rise in EVs means a rise in the overall demand. For households it could be a level of doubling or even tripling the consumption.

Correlation: The demand for an EV has a very different profile than those of the household consumer. It has a high power demand and stays connected for a long and unbroken amount of time. This means the number of EVs will have a high impact on the grid.

Battery size

The size of the battery will state the maximum limit of the added demand from the EV. However, the daily demand will depend on the use of the EV the time of connection, e.g. the user.

Dependency: The type of battery is selected by the EV producer when designing the car. A change could arise from customer demands or legislation, but mostly financial concerns and technological limits define the battery.

Grid impact: A larger battery means a higher limit for the maximum demand.

Correlation: The battery is under development since the EV is a technology in its start-up phase. This means the producers will try various forms and select those with the best business cases, and for a period the types of EV battery will vary until alignment occurs.

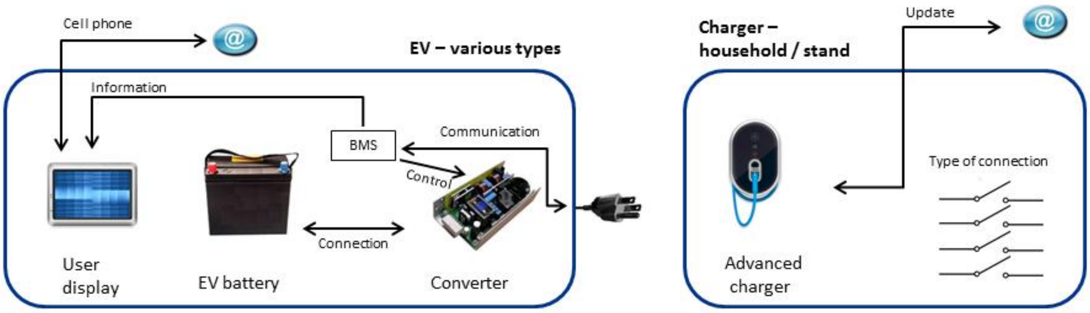

Figure 4.1.1 A simple representation of elements in the EV and charger in an advanced stage of mode 3. The charger has a communication link (Update @) and established three phases plus neutral even if the EV does not require this, yet. The connection includes a communication cable for the charger to agree with the BMS. Information from the EV is possible (Cell phone @) e.g. to the user.

Converter for charging

The converter is the element which is in fact connected to the grid. It consists of several components for intake of a certain power, typically 230V, ~16A single phase AC and converts it to DC in the form the battery accepts. The Battery Management System secures a charge compatible with the battery

Dependency: The converter is selected by the EV producers and is usually chosen as small as possible. Incentive to change the converter could come from customer demands or legislation. Same goes for BMS.

Grid impact: The converter has a high and direct impact on the grid. The properties of the converter determine the noise, e.g. power factor and harmonics, transmitted to the grid and also limit the type of electricity input in both voltage and current.

Correlation: The converter acts as restrain for other parameters and possibilities since it determines the electricity input to the car. Furthermore, the BMS controls or limits the charging procedure and will have to be involved when changing the EV.

4.1.2 Parameters defined by charging

Name of parameter	**Description**
Charging power S_{ch} [kW]	The power which the EV consumes from the grid -may vary up to this limit. The power could be AC or DC, single or several phases, depending on the converter.

Charging time T_{ch} [h]	The time frame for a single charge to full battery capacity is reached.
Charging profile, CP	A charging profile for a number of EVs: typically a curve depicting demand per hour or 15 minutes during a day [kW]/[h]
Energy Consumption E_{ev}	The consumption of energy for a specific amount of EVs for a charge or in a time frame.

Table 4.1.2 Parameters defined by charging

Charging power S_{ch}

When the EV charges, it will receive a particular current from the grid, at the voltage level for the grid. These set the power limit for the charger to receive from the grid, and the BMS will ensure the power is no greater than what the battery may withstand. The charging power is in general at maximum limit; however, charge management may reduce the power either as a setting in the charger or by control, see following section regarding management of charge.

Dependency: The limit for the power is determined between the grid connection and the BMS. A change will require another converter/battery or a different place of connection. The *charging power* is the power upon which the converter and grid has *agreed*.

Grid impact: The charging power is instantaneous and determines the size of the consumer when seen from a grid point of view. The battery sets the limit of energy demand, but the power determines the rate of delivery, which means that the grid will have to deliver the power as long as the EV is connected. A high power demand will have the usual impact on the grid concerning voltage and frequency,

Correlation: The charging power is a critical parameter concerning charging process. It affects the interface with the grid, the time of a charge and thus the user experience, and is affected by all the above parameters and more.

Charging Time T_{ch}

Describes the time frame from beginning to end of a charge which fills the battery to maximum from its current state. Varies for each EV and for each charge of EV according to prior use and charging power available at PCC.

Dependency: The time depends on the state of the battery and the charging power. To change this parameter one will need to change the condition of those.

Grid impact: The time frame for which the grid needs to deliver the charging power in the point of connection of the EV. The relation is thus not a direct impact but a parameter closely related to projection of demand and the user's convenience.

Correlation: For planning and control purposes the charging time is an important parameter. Since the start-up time in general is determined by the user so far, and the end depends on the depletion of the battery which is also dependent on user behavior, the time frame is difficult to predict without any level of control.

Charging profile CP

The charging profile for an EV is actually consumption measured over time, typically for a calendar day. The demand is shown the same way as ordinary consumption; averaged power use per hour for an entire day or days. Parameters such as charging power and charging time can be found in the profile and energy consumption calculated as the area under the curve, see Figure 4.1.2. For further investigation see Annex 2.

Dependency: The charging profile will depend on charging power and time frame, since it is basically a combined representation of the two. The user behavior or time of use will determine the profile, and if there is some sort of control to fulfill a strategy, this will also change the shape of the profile.

Grid impact: Directly related to the demand from the grid since the charging profile is the demand curve for the EV. Locally in the grid, risk of overload may occur with the accumulated demand, since adding the charge profile according to user behavior results in a demand profile which is critical for the low voltage grid.

Correlation: Charging profile is particular an important parameter when debating planning of production, projection of demand, and any strategy or control tools used to influence them both. As a data set the profile is squared and rather simple if no charging power regulation is present and the profile is for one EV. Accumulated, the charging profiles can be described with statistical tools.

Energy Consumption E_{ev}

Energy consumption for an EV is the energy which has been used from the battery and is thus missing. The range will be from zero (just charged) to battery size (totally depleted). The SI unit is Joule, but often the energy is stated in kWh (1 kWh = 3.6 MJ) and the energy delivered to an EV depend on the charging power S_{ch} and the time it has been charging T_{ch}.

Dependency: The energy demand depends on the EV and the use of the EV. A change in demand is depending on the user and shifting the demand will depend on the user and the level of control of charge.

Grid impact: Directly related to the demand from the grid since the energy demand is the product of consumption and time.

Correlation: The energy demand is the product of consumption (kW) and time (h) of the charging procedure. The total demand cannot easily be changed but a shift is possible, as seen in Figure 4.1.2. It relates current, charging power and energy consumption and shows four variations of a charging profile for the same EV.

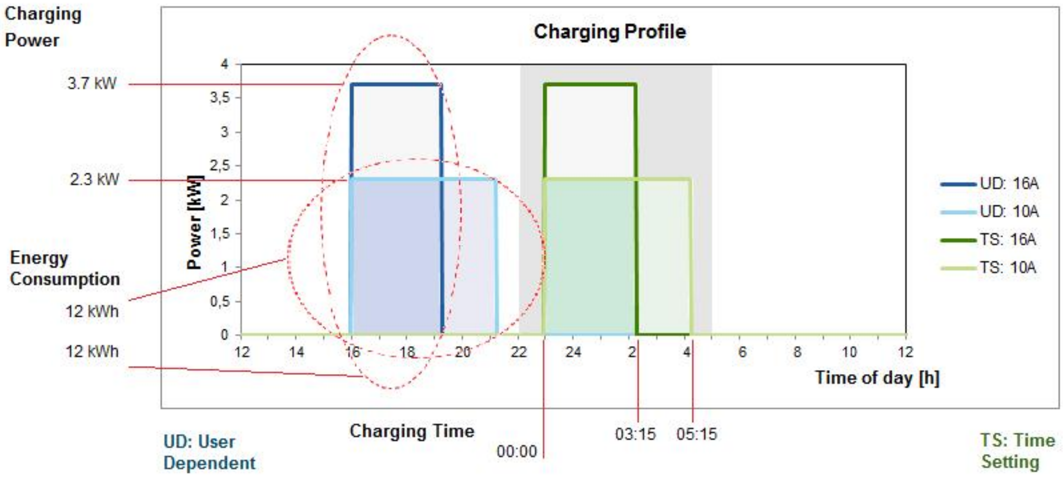

Figure 4.1.2 Shows and example of 4 charging processes with 4 charging profiles for the same EV. The parameters S_{ch}, E_{ev}, and T_{ch} can be seen as well as their relation and impact on the charge. TS shows the charging profiles shifted to the night time.

The relation between power P_{ch}, energy demand E_{ev} and time for a charge T_{ch} can be seen in Figure 4.1.2. The first two charging profiles marked in blue, "UD:16A" and "UD:10A" derive from the user connecting the EV at 16:00 when returning home. The EV is 50% depleted and needs to absorb energy equaling 12kWh. If the connection allows *a current of 16A*, the charging power is 3.7kW and the charging is done at approx. *03:15 time frame*. If the *current is limited to 10A*, the same amount of energy (E_{ev} = 12 kWh) will take *05:15 in charging time.*

If the connection allows a time setting delay (TS) the same two CP can be done at night time, in the figure shown in gray with the CPs in green. The charging process with a larger current, marked with a darker curve, is again 2 hours shorter than the low current charge for the same EV. It is important to note that *the energy demand depends on the EV* and does not change when shifting the charge. The CP depends on the charger and charging parameters while their timing may depend on the user, or other settings used to manage the charge.

These parameters are further explained in the following and investigated in Annex 2.

4.1.3 Parameters related to Charge Management

Name of parameter	Description
Charging Management Strategy, CMS	The strategy or philosophy of how to charge many EVs in order to reach a goal. A strategy is thus defined by actions with a purpose.
Charger intelligence CI/CAI	The term Intelligence or Artificial Intelligence points to the programming level of equipment. This includes the software (and CPU) which controls the charging procedure and interaction with stakeholders. AI usually means the programming itself can choose the best course of action according to its data and possibly a database of events in prior scenarios.
Fast Charger	Mainly the term covers DC fast charging stands which connect with a large current and fills the battery e.g. in less than an hour.
Price of Electricity	The costs of i.e. a kWh when sold on the market or to the consumer. The price is set by the market for each day ahead or by a contract.

Table 4.1.3 Parameters related to charge management

Charge Management Strategy, CMS

A strategy for charging determines the goal for adapting the charging such as user friendly and grid friendly charging by charging when other residential load is low. A strategy requires a plan; it could be to charge at night and this leads to a method, which in this case would be to alter the charging profile of the EVs so the active part is at night. This can be seen in Figure 4.1.2 where the tool used is Time Setting (TS) e.g. by a setup of the software in the charger that automatically starts the charge at 23:00.

Dependency: The strategy involves either a user act or programming for EVSE to support their behavior according to the strategy. A change in strategy will thus involve the user behavior, the EVSE and a change in software or software features (see explanation of CI in the following section).

Grid impact: The strategy will have a great effect on the grid, depending on the level of establishment and congruity of strategies in the particular grid area. Effectuating a strategy is done according to a plan with a method to aid the grid; a change in CPs for all EVs. Thus the grid impact should be positive, but the level of complexity is high and further investigation is needed.

Correlation: Since the strategy may or should control both software and user behavior, the correlation to other parameters is strong and broad. However, the level of effectuating a strategy directly depends on the tools available for EVSE such as hardware, software, CI and also the behavior of the user. Choosing a strategy will not necessarily change anything, but the plan for fulfilling the strategy and the method of effectuation suggest the CMS has a profound correlation with other parameters. For a graphical representation see Figure 4.1.3. If one wish to affirm the effect of a CMS the accumulated effect of the tools must be evaluated, since changing a parameter (start charging at 23:00) may have a negative effect on some other parameter (the total load at 23:00 changes suddenly) and this may corrupt the original goal of the strategy.

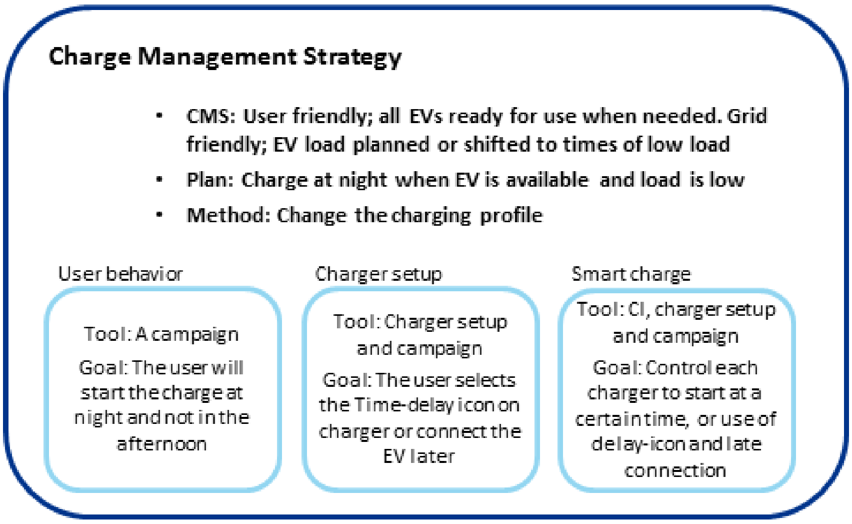

Figure 4.1.3 A graphical representation of charge management strategy, the plan to succeed, the choice of method and which tools to use in order to fulfill the strategy. Depending on the strategy, more than one method or tool may be needed but in general only one CMS should be in effect.

Charger intelligence or Artificial Intelligence CI/CAI

The term covers an integrated CPU with ROM, RAM and sufficient software and memory to reach an advanced level of programming. Ordinary actions for achieving best course may then be decided by programming and not i.e. human actions. Often simple approaches such as a time delay of a pre-programmed set of actions are covered in the term "smart charging" or "intelligent chargers" though the common definition of AI is more restrict. If the programming includes means of learning; a memory bank which further records which reactions prior have been proven best in certain situations, the programming can reach a level of autonomous actions corresponding to intelligence, thus artificial intelligence.

Dependency: The intelligence level of a charger or how smart, fast, grid-friendly etc. it can be depend on the equipment; CPU, software and memory. Since these units are in the charger they will be spread countrywide and an upgrade will mean new chargers and high expenses. A communication link for remote control or software update as shown in Figure 4.1.1 could make them CI-ready. Establishing CI requires communications and the greatest dependency will be/become properties of this communication.

Grid impact: The grid will have a widespread reaction from CI depending on the strategy in effect and the method of executing. In general, smart charging is done to make the EVs more grid friendly, to have methods of actions within the restrains of the grid, and in this case the CI will help with a higher level of exploitation of the established grid and less pressure for reinforcements due to EV penetration.

Correlation: The level of CI depends on what suits the entire business case of EV and EVSE, since more advanced equipment equals more expenses. If only a simple choice of smart charging procedure is needed, the mode 3 charger already on the market may be sufficient. However, to prepare for the future the chargers should be at least CI-ready, since the charging strategy is seen as parameter with critical influence in the future, and this depends on the level of intelligence in a smart charger.

Fast Charging

The term fast charging insinuates that the charging is done at a stand. Fast charge stations are typically high DC (or AC) chargers with an outlet that fits EVs with fast charge abilities (plug). Fast charging can be done with charging power S_{ch} as high as 50 kW and T_{ch} just short of 30 minutes.

Dependency: The type of fast charge stations are determined by EV technology providers, EV producers and possible good infrastructure locations (grid/road). A change in the fast charge abilities depend on the EVSP, EV producers, the user, and to some extent legislation.

Grid impact: The main impact is the very high demand in power which, depending of the location, may change the consumption pattern significantly. However, the time frame for a charge reduces significantly.

Correlation: The fast charge stations are related to a certain type of EV and are thus correlated to charging power and time. Mostly, the development of fast charging will have an effect on grid and EV penetration.

Price of Electricity

The price of electricity is the costs for an amount of electric energy bought by a user or a vendor. The price reflects the balance between demand and supply and is high when the demand is high or if there is a lack of production. If an electric market is established the price is calculated e.g. for each hour in the day ahead/ the next hour. Usually residential customers have contracts which do not consider any dynamic pricing during the day. Energy will be sold at a constant price (or two tariffs per day with constant prices for fixed timeslots) thus this parameter mainly affects the retailers which then correct the price for resident consumption.

Dependency: The price relates on financial considerations and area or country. One kWh may vary in price e.g. in Denmark and Germany, in the morning and afternoon etc. The variation in price for a user will also depend on legislation e.g. taxes and tariffs.

Grid impact: The price does not have a direct grid impact, even if there is a relation. The difference in price between countries will have an impact on the export/import which again will influence terms such as regulation power.

Correlation: The price is related to the users but has no direct strong correlation. The demand curve for each hour is very vertical since the flexibility is low for consumers; the energy is needed when it is needed and the production must follow to maintain the balance. This means the grid must have a capacity to transmit the energy and often this is the basis of the structure of the grid.

4.1.4 Parameters contained by the Grid

Name of parameter	Description
Consumption S_c [kW] or [kVA]	The general consumption of electricity in a given area or grid at a given time, often shown as hourly values during a day.
Production S_p [kW] or [kVA]	The general production of electricity in a given area at a given time, often shown as hourly values during a day (will match the power consumption except when importing/exporting).
Grid topology	Grid topology covers the setup or construction of a certain grid, including sizes (capacity) of each component. It can also include a general layout such as a mesh or branch structure.
Capacity	The capacity of a grid various with the size the components and the level of voltage etc. And is often given as a rated current or power at or near a fuse. If the capacity exceeds the load there is a surplus of capacity which may be exploited.

Power Quality PQ	A set of parameters which describes the quality of both current and voltage signals, including flicker, voltage unbalance, harmonics etc.

Table 4.1.4 Parameters defined by Grid Components

Consumption S_c

The consumption of a grid is given as a power and can be e.g. calculated be adding all the power in use for all consumers on the particular grid, see right side of Figure 4.1.5. If measured over time and given as an average of each hour, the consumption is often given in kWh for each hour of the day and depicted in a graph as a consumption curve. Calculating the average means that the maximum *power* demand [kW] may be higher than i.e. for a time frame than the *average consumption of energy* in kWh. See also Annex 2, were a load curve example is given.

Dependency: The consumption varies according to the demand from society and is not easily altered or shifted. The demand curve used for projection as practically vertical for each hour and the general shape of the consumption curve is well known and based on our daily behavior.

Grid impact: The consumption is the amount of power (or energy per time unit) which is absorbed by the grid if there is no import or export. If the consumption rises quickly and the production does not keep up parameters such as the synchrony, voltage, the frequency, etc. will be affected.

Correlation: The consumption is strongly related to production since these two parameters must be in balance. Furthermore, the consumption is a result of human behavior and must be projected to have the needed production ready. Ordinary residential consumption is an accumulation of a vast amount of smaller units, but the EV will change this for the ordinary household.

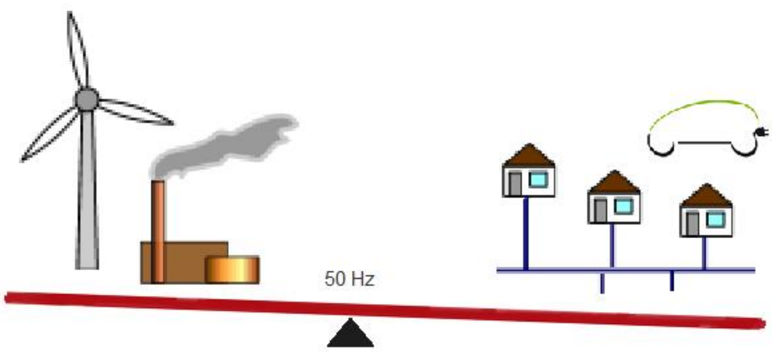

Figure 4.1.4 The production on the left and the consumption on the right must be in balance all the time to avoid negative impact on the grid. Here the frequency is dropping below 50Hz after adding the EV in the residential grid.

Production S_p

The production is the accumulated power from all production units connected to grid. Seen over a time period this gives the energy production. These are ordinary larger than typical consumers and the grids contain various types; fast units to react quickly to changes in consumption and large rotating units to keep the grid robust. See left side of Figure 4.1.5 for a single unit supplying a small radial.

Dependency: The production depends on the units connected. It is planned according to the electric market and to match the projected consumption. Furthermore, regulation power is used to balance the grid every hour of every day to maintain the technical balance, see Figure 4.1.4.

Grid impact: The production raises the voltage level at PCC and must match the level of consumption to maintain balance. This regular requires some fast production units such as gas turbines, and rotating elements provide stability to the grids frequency.

Correlation: The production relates to the consumption. The balance between these two affects many other parameters in the grid and is a critical element to withstand fluctuations in voltage and other risks of failures.

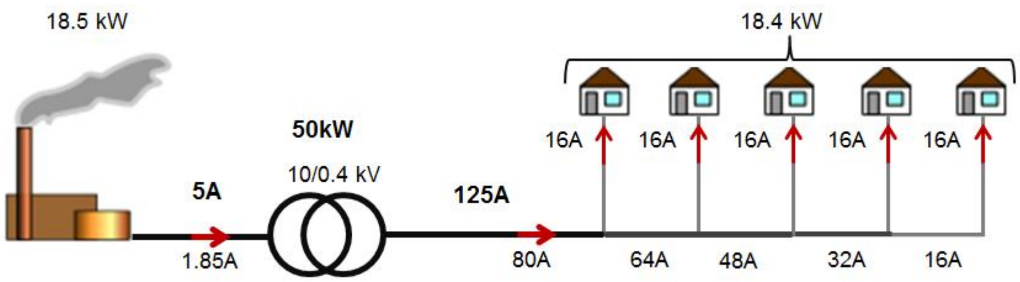

Figure 4.1.5 A small radial with 1 production unit P_p at 18.5kW and 5 consumers with P_c = 18.4 kW. The grid loss is 0.1kW in the lines and transformer. The capacity of the transformer is 50kW making the surplus capacity ~30kW. For the radial it is however 45A.

Grid topology

The topology covers the setup and components of a grid, e.g. the size of each cable, the length of each line, the type of each transformer etc. in the grid. Properties such as voltage level and structure are also included.

Dependency: The topology depends on physical properties of the grid components i.e. the hardware which is established as part of the grid. A change will require that the particulate component is exchanged with another. If it is e.g. a 400kVA transformer this would mean the DSO will plan, execute, and finance the update.

Grid impact: The grid topology *is* the grid which is to say every change in topology will change the grid.

Correlation: A change for one component may change the entire grid capacity in case of e.g. a bottleneck or a change from radial to circular structure.

Capacity

The capacity of a grid is an overall view of the capacity of each element. If a transformer can transmit a current of 150A but the cable connecting has a current limit of 125A the current is limited to 125A to not damage the cable. It is common to have the capacity decrease through a radial as seen in Figure 4.1.5 A small radial with 1 production unit Pp at 18.5kW and 5 consumers with Pc = 18.4 kW. The grid loss is 0.1kW in the lines and transformer. The capacity of the transformer is 50kW making the surplus capacity ~30kW. For the radial it is however 45A. Figure 4.1.5 by the cables becoming smaller (lighter in color) the further away from the transformer.

Dependency: The capacity depends on grid topology and the point and direction in the grid which the consideration includes. In general a higher voltage means a higher capacity, and if the capacity must be changed the restricting component must be exchanged.

Grid impact: The capacity has a great impact on the grid. The bigger a capacity the "stronger" a grid, the more energy it can transmit, and the larger the components.

Correlation: Capacity relates to almost any other parameter which concerns the grid. Besides the capacity being of interest, the surplus capacity is also very important. When the grid is not at maximum load, the capacity is greater than the consumption and this indicates a space for more consumers. However, the *surplus* capacity depends on the time frame and the grid and can often be found i.e. at night time when the household and industrial consumption is low.

Power Quality PQ

The parameter PQ includes a set of factors used to describe the state of the grid in a particular point. This includes problems such as flicker, harmonics in grid parameters, voltage fluctuations, and other electro technical terms. In general the PQ can be used to describe e.g. if the grid of interest in near a limit, has a fragile state and other scenarios which means attention or action is required.

Dependency: PQ depends on the grid and point of measuring. The state of PQ involves other parameters such as limit for e.g. harmonic injection and depends on every component connected to the grid. Their significance again depends on their type and proximity and a change can be difficult to obtain. If the poor PQ is traced to a particular component, this can be exchanged; otherwise counter actions must be taken.

Grid impact: The impact on the grid is of importance but rather complex since a poor PQ puts pressure on an amount of other parameters this including a drop in voltage, a too high current etc. The grid has some flexibility and a poor PQ may be within limitations but still require actions for instance supervision in the affected area.

Correlation: The PQ especially derives from power electronics and elements with a high inrush current, but also large consumption or production units, a significant use of reactive power, etc. A poor PQ can also lead to a positive feedback loop i.e. bringing the affected components into a state which has an even more negative impact on the PQ. In general terms the PQ is often used as a parameter which indicate the need for action; supervision, control or perhaps new or more hardware.

In Annex 1 the parameters can be found in an overview with a short description and recapitulation as a tool for look-up during debate. It shortly states the description and impact as a summary of this chapter but it does not relate the total connections between parameters.

For a further investigation of the complex matters of charge management strategy, charging profiles and the tools of calculating them, see Annex 2. This investigates and uses the various parameters with the focus of calculating profiles for a low number of household loads and profiles for EVs. The calculations exploit statistical tools to reevaluate the curves often used to calculate or simulate on the impact of EVs, which is based on assumptions of concurrency and mean values that do not comply in small grids such as a single radial on low voltage.

These investigations are needed in order to change the way of planning for the low voltage grid; the use of the grid is changing and the new complexity demands more of planning and supervision in the low voltages. This is the topic for the next chapter.

5 Planning the future for the Grid with EVs

The electric infrastructure in a country is of great importance and in distribution level it is undergoing a change in use and service. The EVs connect at the lowest or lower levels were the grid is not constructed to a consumption of this type. As long as the penetration is low, the negative impact is low as well, but it is paramount to plan for the DSO if the distribution grid is to maintain its high level of service and security.

In this chapter follows a discussion regarding the interface between grid and EV seen from grid perspective i.e. with the DSO as the important stakeholder and the actions which must be considered by their planning department.

The discussion is based on a survey performed by the partners[3] in the GeM team in order to reflect the considerations for DSOs in Europe. However, the critical parameter may vary between countries and even between local grids, since the grid topology is the foundation for the possibilities and challenges for the interface to EVs.

5.1 The Challenges regarding Projections and Planning

From a planning point of view, the prognosis for the use of EV, amount and time of day, is uncertain since the basis for a general household consumption does not comply in terms of concurrency and dispersion, this rendering the known algorithms for consumption projection insufficient. Particular concurrency is difficult since charging of the EV battery is constant and not as e.g. a stove, water heater, or refrigerator based on short-term repeated cycles. The time of day is controlled by the user and leads to a case of business as usual which means the user will connect the EV at the same time as other high level consumers; the stove, the heater etc. Since this means the grid reaches its capacity limit the impact is high regarding investments and time frame for adapting to a high EV penetration.

This new element is among a group which also includes other large consumer units such as heat pumps and micro VE (solar cells) posing a similar challenge on the low voltage grid but on the production side. These new elements may have a slow or fast penetration rate but all change the usage of the low voltage grid and through this how the DSO must

---

[3] Enel Distribuzione, Italy; Iberdrola Spain, RWE Germany; and by Danish Energy Association: DONG Energy, Denmark; Seas NVE, Denmark.

plan for the future. The short term and long term view is described in the following, however a point of common agreement is the need for a tool which can aid in the planning both for day ahead, but also in terms of years. This tool will need a basis of data, which could be gathered by AMR or simulated.

In Annex 2 a statistical approach has been used in order to investigate the household charge and setup, were the EVs are added at outer limits of the low voltage grid; at radials which are not designed for such high power transmittance and were surveillance is rare. The study case clarifies the relation between the use of EV, the strategy of charging, and the impact these parameters will have on the grid. Terms as driving patterns, discharge level of the battery (SOC) and the time of charging are all further investigated.

5.1.1 The short term challenges

For the very short term, the grid and so the planners do not foresee large problems with the new elements. An EV charges in general at a power level low enough to not cause particular problems, as long as the penetration is low.

In a slightly longer time frame, the placement of consumption will pressure the grid, in particular locally if every household on the same road (radial) acquires an EV. As seen in the previous chapter (see Figure 4.1.2) the general behavior of the user will place the EV's CP (UD) in times of peak load, and the grid is likely to experience problems. In some grids this will be the voltage becoming too low first, and then the capacity coming up short but in others it can be the other way around or entirely different.

The number of EVs for the first problems to occur cannot easily be projected but the first signs are known by the DSOs and some reactions considered which the discussion following will describe.

5.1.1.1 Incite Grid friendly behavior

If the EV puts pressure on the grid this may be solved by a grid friendly behavior. An alternative is reinforcing to remove the pressure but this is seen as the final action for the DSOs at this state.

The grid friendly behavior could be obtained by affecting the user through campaigns or by a technical solution. The technical approach will mean the interface i.e. the charger should have some options and here many solutions are possible. It could be a possibility provided to the user, as in some mode 3 EVSE with a "delay charging" icon to shift the consumption to start at a certain time. However, as the Study Case in Annex 2 show, this may also pose a challenge to the grid. The DSOs do not know where or how their grid is affected and this is also an aspect which has been discussed.

5.1.1.2 Adding supervision and gathering data

A total supervision of every low voltage branch is not possible due to sheer number and no direct (financial) benefits from the equipment needed. However, the lack of knowledge leads to a wide use of other tools; statistics, algorithms, etc. which may or may not be proven correct.

A possibility for the DSOs could be adding supervision to particular places in the grid. The possibilities are many but it could be an area with suspected problems and the gathered information can be used to establish knowledge particular regarding the EVs. Collecting data with a particular purpose could lead to new tools based on algorithms and data. The ordinary consumption is known very well due to investigations based on similar procedures and has competence which include how S_c vary even according to weather; cool summers or cold winters. With AMR it is possible to receive data from a large number of consumers for further processing and it is a possibility for the future planning of production regarding the EVs.

The experience and prior knowledge which the DSOs have regarding their particular grid may provide the grid with sufficient strength as EV penetration rise, particular since this may be slow. However, the tendency in the transportation section indicate that the EVs will soon, compared to the lifespan of electric components, reach a level were more advanced tools are needed, and the subject of long term planning arise.

5.1.2 Long term challenges as penetration increase

The subject of long term planning for the DSOs are important and many suggestions for possible challenges, mitigation measures and solutions can be found in projects, articles and by discussions of energy politics. The future of electric energy is on the agenda, and the future of the EV as well, which means projections of penetration for the EV may be rather uncertain. The expected effect on the grid when reaching a high level can however be anticipated by those in the energy sector, and various scenarios cause the DSOs to reflect upon the results.

What if every household one day has an EV? The limitation for the low voltage grid becomes the capacity of cables and transformers and other critical parameters such as maintaining the frequency and a proper voltage. Those are most likely to cause critical failures and can be resolved by having capacity in the grid.

5.1.2.1 Using tools to plan the future of the grid

The DSOs foresee a need for tools designed to include the EVs. This can relate to all parameters but would include the capacity and the voltage. Since expanding the grid is slow progress and have significant financial impact, it is important to reinforce only when needed and at critical points in the grid. This way the capacity of the grid will increase as the EV penetration rises.

Other tools may be needed as well. If established, one could image a selection of actions: perhaps the chargers themselves can aid the grid, by the use of a strategy. The concept of a smart charger is already the topic of a variation of debates (Smart Grid).

5.1.2.2 A nationwide strategy for the EVs

Since the penetration of EVs is still low the challenges for the grid is still open for discussion but many considerations for solutions is an exciting topic. The properties of both charger and EV has been discussed with DSOs and alterations suggested. The converter and the charger is the element which will affect the grid, and the process of charging. If the DSOs can gain influence on these, the consideration for the grid can rise.

The actions could include the EV; a different converter will open up the possibility of three-phase charging for a better balance between phases. A better converter emits less noise to the grid for a better PQ.

The charger can become intelligent and help by receiving data from the grid or the DSO and act accordingly. A market can be established to financially incite the EMO or vendors to create control opportunities. For a nationwide affect legislation can be changed in order to increase the functionality of the grid. Perhaps a smart grid is the future.

5.2 A perspective for the EV and Grid in the Future

Planning for the future depends on the wishes of stakeholders and the prospects of business cases. Levels of technology is also important and the management of the vast amount of EVs to come. The users of EVs may wish for a large distance and easy charging even across borders. The vendors may wish for a large amount of EV types and a good business case. In politics the topics from EVs may be the expected benefits for the environment. From an electric point of view the grid and the DSOs may seek solutions to problems of technical character and cannot rely on the users to comply and act grid friendly. All of these considerations reveal a need to be ready for the future.

Seen from the future grid point of view, the DSOs will need tools, knowledge, and answers in general. In this investigation the parameters which relate to the grid and EV have been described and analyzed for correlation and impact. Some parameters show a clear development as EV penetration rises, but others display a complexity level which makes the projection very difficult. The DSOs foresee the need for mitigation measures, but before these can be planned the challenges must be analyzed and this requires more data, more knowledge and a further basis to project from.

Some issues regarding the EVs are easy to relate to; the user friendliness, and even the grid friendliness, but the benefits and drawbacks of a high penetration can be difficult to state.

The importance of a good interface is clear, but the demands for this interface must be based on analysis in order to reach the best solutions. Investigations and projects throughout Europe are even now making further progress on defining the challenges and describing possible solutions, for the best grid of tomorrow.

6 Appendix

6.1 Annex 1 – Overview of EV Parameters

	Parameter	Description	Relation to grid	Impact
EV	Number of EVs, N_{ev}	The number of EV's either on a radial, in a grid or in a country	A charging EV is a consumer so the number represents added consumers [num]	A rise in amount give cause to a rise in the demand and other effects from EV consumption
	Battery type or size B	The battery described as size or capacity of energy	The maximum total consumption per charge of EV [kWh] if it is 100% depleted	A rise in size give cause to a rise in the demand limit
	Converter C_{ev}	The converter which connects the AC grid to the DC battery. Often also include the software BMS which manage the charging procedure.	The converter is connected to the grid and convert the AC current to DC	Noise, harmonics etc. will be rooted in the converter; the more it produces the more the grid is affected
Charging	Charging power S_{ch}	The power which the EV consumes may vary up to this limit. The power is AC/DC, single or several phases, depending on the converter.	The instantaneous level of power consumption [kW] or [kVA]	A rise in charging power causes the instantaneous demand per EV to rise
	Charging time T_{ch}	The time frame for a single charge to 100% battery capacity is reached.	The time frame of demand from the EV [h]	A rise in charging time means a longer period of the EV being a consumer in the grid.
	Charging profile CP	A charging profile for a number of EVs: typically a curve depicting demand per hour or 15 minutes during a day.	Given in kW/h the charging profile is the demand curve for an EV. [kW / h]	A change in profile affects the grid locally and in general
	Energy Consumption E_{ev}	The consumption of energy for a specific amount of EVs for a charge or in a time frame.	The energy which the EV require by the grid in the speed of S_{ch}	A high energy demand means a higher consumption / a longer time of charge
Charge Management	Charge Management Strategy CMS	The strategy or philosophy of how the charge of many EVs should be done in order to minimize negative effects on the grid	Via S_{ch}, T_{ch}, charging profile and the control options such as changing S_{ch} or T_{ch}.	A change in strategy affects the entire behavior and state of the EVs
	Charger intelligence CI/CAI	Includes in general the CPU and its software which controls the charging procedure and any interaction with stakeholders.	Since the "intelligence" is actually a means of control or coding, there is no direct relation.	The impact of CAI will be substantial since the ability to control the EVs affects other parameters which do relate to the grid.

	Parameter	Description	Relation to grid	Impact
Charge Management	Fast Charger	Mainly the term covers DC fast charging stands which fills the battery e.g. in less than an hour.	When charging the FCSE becomes a large user of power at high current.	The higher the charging current the more solid the grid at PCC must be
	Price of Electricity	The costs of i.e. a kWh when sold on the market or to the consumer	The costs [£] are not directly grid related but are connected to the supply and demand	A rise in price gives cause to a rise in supply (or a higher demand cause the rise in price and supply)
Grid parameters	Consumption S_c	The general consumption of electricity in a given grid at a given time, often shown as hourly values during a day.	The consumption for an area in power [MW] at a time or in energy [kWh] for a time frame.	A rise in consumption may locally cause a voltage drop and in general rises the demand for production
	Production S_p	The general production in a grid at a given time, often shown as hourly values during a day (will match the power consumption except when importing/exporting).	The production for an area in power [MW] at a time or in energy [kWh] for a time frame.	A rise in production may locally cause a voltage rise and are in general corrected according to demand
	Grid Topology	The setup and components of the grid including size	The topology is every detail of the grid	A change in topology affects the grid properties
	Capacity	The capacity of a grid various with the size the components and the level of voltage, current etc.	The “size” of the grid, often given in current [A] since voltage varies, or in power [W]	A high capacity raises the limit for consumption in the grid
	Power Quality PQ	A set of parameters (harmonics, voltage, flicker) which describes the state of the grid and the likelihood of certain types of failure.	Particular related to voltage and is affected by elements on the grid	A poor PQ reveal voltage fluctuations which stress grid components and may cause error or collapse

6.2 Annex 2 – The impact of Charging Strategies

To measure the impact of charging EVs, the traditional approach is to account for large number of EVs in a population. That is, a large EV fleet population is used to quantify the factor of impact, by constructing a charging profile for the entire population, which represents the supplemental consumption to the traditional one. This approach gives a relative and sufficient picture of the aggregated load on the power system in larger regions where energy consumption is fairly high, but these regions cover everything from countries and cities, to radials on the distribution network with a high number of residence.

However, if the total consumption on smaller scales, i.e. on low voltage grid where each consumer has a significant effect on the grid, the traditional approach derived from the EV fleet population by averaging, loses its properties. Hence, the approach cannot be applied to reflect realistic charging profiles for the fairly small number of EVs with available connectivity to a low voltage grid.

In this section, the objective is to point out the fault approach of the traditional population average method when the population only includes very limited number of EVs with connectivity to a low voltage grid. This is demonstrated with a simulation study, which is performed by random sampling from a large population of EVs, but the sampling (also occasionally referred to as subsampling) is a statistical technique for obtaining information about a population from composition of limited number of random samples from the population. Hence, a large number of replicates, of a predefined number of subsamples, are taken from the population to grasp the properties of the sample group, conditioned on the sample size. Here, the size of the subsample corresponds to the number of vehicles that are connected to the low voltage grid at the same time, i.e. the focus is not on the cars, but on the number of charging stations at residents with connection to the grid.

The following simulation study utilizes information from the general population, where the most important parameters are for each EV used in the simulation, that is:

1) The time of arrival at the charging station.
2) The energy consumption at the time of the arrival.

However, no population data is available for the study, and the alternative is to retrieve the subsamples in the simulation study from a synthetic EV fleet population.

6.2.1 EV fleet population

The EV fleet population is simulated with the sole purpose of providing the EVs in the subsample simulation the required parameters. When measures for the properties of EVs in a population become accessible, they can be substituted with the synthetic EV fleet population and give a more realistic results for the CPs for the subsamples.

To arrive at an EV fleet population, that gives a reasonable picture of a real-life scenario, several assumptions have to be considered:

- All sample groups contain EV users that drive to work in the morning and return in the afternoon.
- All EV users spent some time at work per day, which corresponds to 100%

Furthermore, the simulation is divided into several independent phases, where each has its own statistical properties, and by aggregating these phases the time of the arrival is generated, as well as the state of the battery in the EV by the time the EV is connected to the grid.

Three independent events are considered as the main predictor for the time of arrival at home, after a working day:

1) Time of departure in the morning

   Over a large sample of EVs, with the assumption that the working hours for the entire population varies from early morning to the afternoon, the time of departure is assessed to be described by a normal distribution, with a standard deviation of 1 hour. By this assumption, 99% of the population drives away from home in the interval of 2 hours before and 2 hours after the mean value. In Denmark the mean value is approximately at 7:30 in the morning.

2) Time spent at work

   The total number of working hours is usually close to 8 hours/day, but may differ from region to region. This number, though, can vary significantly from one person to the next in the population, as well as on an individual level there is a great difference from one day to the next. Thus, the time spent at work has to be both positive where the uncertainty increases with the average number of working hours. The simplest approach for simulating the working hours is by assuming a Poisson distribution for the time spent at work, where the standard deviation increased with the square root of the average number of work hours.

3) Time spent on driving to and from work.

   To evaluate the distance that each EV in the population drives, a gamma distribution is applied, since it provides a probability distribution for the driving distance that is similar to driving patterns observed in studies in the literature. By fitting a relationship between the average velocity of the vehicle and the driving distance, the time spent on driving can be estimated.

The third event also provides important information for the SOC, since the driving distance is calculated in this step of the simulation process. Hence, by knowing the driven distance, the energy consumption for the EV can be assessed. By default assumption the EV is only charged at residents, however, in the few cases (approx. 2-3 %) where the distance driven during the day is larger than the battery capacity, the surplus use of energy is assumed introduced to the car during the hours where the EV is not at the resident charger. This could be a charger at work, at a shopping center or by a hybrid car e.g. an internal source. The specific source is not important in this study since they all have in common that the source is *not* at home charging e.g. the considered grid is *not* affected no matter the choice of 2.nd source.

The aforementioned assumptions result in the two distributions for the time of departure in the morning and the time of arrival in the afternoon, as displayed in Figure 5.2.1. The differences in the shape of the two distributions indicates that the variation in the work hours and the varying driving patterns of the individual EVs in the population, provide a higher variation in the time of arrival, compared to the variation in the time of departure the same morning. However, this variation is fairly small in relation to the size of the population since one of the assumptions states that the whole population is represented by people who deliver 35 to 40 working hours per week, corresponding to 100% employment. The alternative would be to account for different percentage of employment, which varies from 50% to 100%, but this is not included in the present study since the primary objective is to illustrate the increased power demands for reduced number of EVs connected to a radial, especially EVs that are connected to smaller radials on 0.4kV networks.

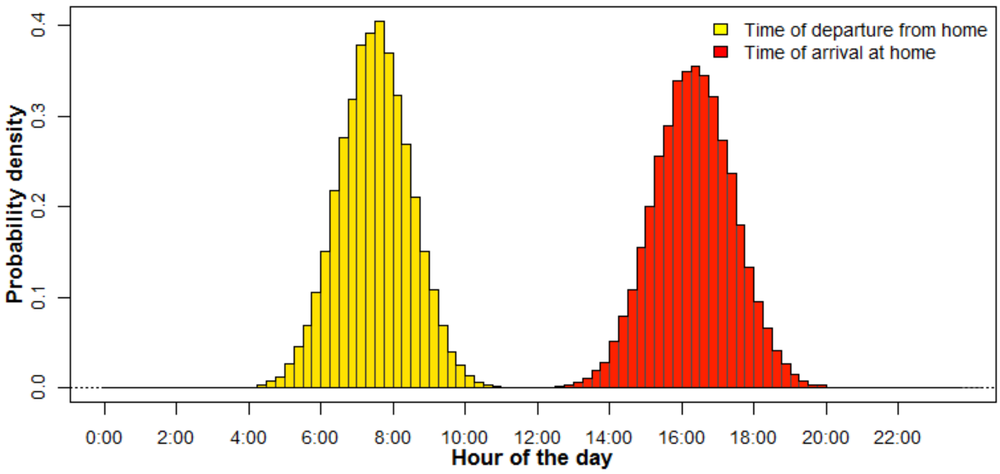

Figure 6.2.1 Illustration of Danish Case: Simulated EV fleet population distributions for the time of departure and the subsequent time of arrival. The variation in work hours and time spent on driving results in an distribution for the arrival time that is more sparse than the distribution for the time of departure.

6.2.2 EV charging profiles (CP) on low voltage grids: A simulation study

When the focus is on assessing the impact on low voltage grid, the neat shape of the population's arrival in Figure 5.2.1 cannot be accounted for by down-scaling the population curve. This is because of the sharp change of paradigm in the charging impact, which becomes more significant with reduced number of vehicles connected to the low voltage grid. Thus, for a small scale grid the impact of the individual EV becomes highly influential in the impact assessment where the real CP for the EV is in its simplest form a threshold, which equals the charging power for the vehicle when the EV consumes energy from the grid. This same CP for the individual EV depends directly on both the time of arrival (which represents the first possible initiation for the time of charging) and the charging time. Hence, if the time of arrival for the individual EV varies substantially, the set of possible outcomes for the CP covers more hours of the day, as well as with increased driving distance the CP is prolonged into the following day. This CP is a representative for the upper limit of the possible outcomes for a single EV, i.e. it is an expression for the maximum effect of a single EV at a given time instant.

The single EV CP, as compared to a downscaled population CP, hereafter referred to as population average, in the top plot of Figure 5.2.2. Moving from the top plot and downwards in the figure demonstrates the evolution of the probable CPs (dark area) for increased number of EVs on the low voltage grid. The very obvious impact of the single EV is substantial up to 10 EVs on the grid. When the number of EVs approaches 20 EVs, the effect of a single vehicle are minimal; and for 50 EVs the effect are negligible, as well as the shape of the probable CPs is approaching the shape of the population average. However, on the low voltage grid, occurrence of 50 EVs connected to the grid simultaneously would be a rare event. Hence, to obtain the probable CPs, corresponding to the upper level of the charging for the EVs on the grid as a function of the time of the day (maximum effect of several EVs at a given time instant), a simulation study is conducted that will generate the range of possible CPs for the given number of EVs on the low voltage grid. As for the single EV CP, the maximum effect of several EVs connected at a given time instant corresponds to the maximum effect for CP output, i.e. the dark shaded area in Figure 5.2.2 represents all sets of possible outcome for the CPs.

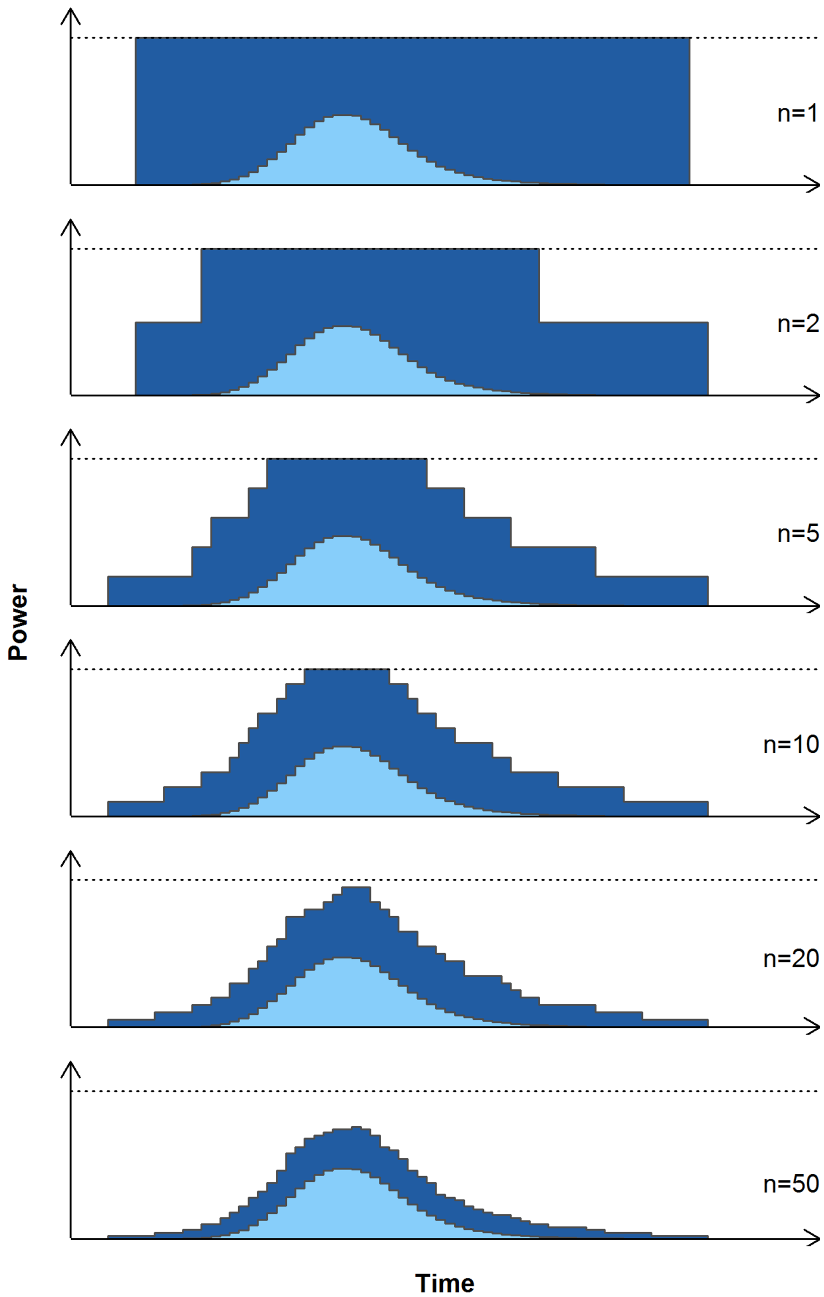

Figure 6.2.2 Comparison between the probable CPs (dark shaded area) and the population average (light shaded area), for n number of EVs on the grid. Top-down shows how the simulated on-off settings for the probable CP of the single EV evolves from being a single threshold (top plot), to a shape that is similar to the population average (bottom plot).

6.2.2.1 Simulation study

For a predefined number of EVs in a sample, a reasonably large number of subsamples are taken from the EV fleet population. For every time instant that is covered by the subsamples the subsample that has the largest impact on the grid is chosen to represent the potential grid impact at that particular time instant. This procedure provides a CP that is dependent on the number of EVs connected to the grid.

Charging profiles

Three charging profiles are considered in this study:

1) User Dependent charging profile.
2) Timer Based charging profile.
3) Load Dependent charging profile.

Deliverable 4.2 “Recommendations on grid-supporting opportunities of EVs”[4] defines different charging strategies, divided into three scenarios, conservative world, pragmatic world and advanced world. The User Dependent charging profile and the Timer Based charging profile correspond to the “Business as Usual” and “Time of Use” strategies from the conservative world respectively. The “Load Dependent” charging profile corresponds to the “Control Loop Control” from the pragmatic world.

To simulate the charging profiles for the different number (*n)* of EVs connected to the grid, a reasonable number of subsamples (*m*) is taken from the given EV population where each sample group contains the *n* EVs. The population size is put to be 50,000 EVs, where all the EV users drive to work in the morning and, subsequently, return in the afternoon. The number of subsamples for each sample size is set to a reasonably high number, $m = 10{,}000$, and the sample sizes are $n = \{5, 10, 20\}$ EVs connected to the low voltage grid.

The simulation study considers three different charging profile, where all EVs in the sample size charge with the same power, 3.7kW, which correspond 16A single phase at a supply voltage of 230V. Traditionally for households on the city or rural networks, charging current is from 10A to 16A, however higher charging powers may be relevant for future EVs .

Scenario 1 – User Dependent

---

[4] Available on Green Emotion website under following link: http://www.greenemotion-project.eu/dissemination/deliverables-infrastructure-solutions.php

The moment after the EV is parked by the charging station, the car is plugged to the grid and charging is initiated. This strategy does not involve any manageable parameters, or parameters for the grid component, and the only parameters that are required are the charging parameters (Table 3.1.2).

The subsampled CP, along with charging profile for the downscaled EV fleet population, are depicted in Figure 5.2.3 for sample sizes of 5, 10 and 20 EVs. The figure shows very clearly the misleading assumptions for a small scale grid impact, as if the CP was to be based on the downscaled EV fleet population curve (light blue). For groups of very few EVs, e.g. the top plot in Figure 5.2.3 for 5 EVs in a sample size, the subsample simulation results in CPs, which in the peak hours are close to twice the magnitude of the population average curves. The shape of the subsampling curves corresponds to the number of EVs in the sample size, due to the on-off settings for the individual charging power in the grouped charging profile.

By increasing the number of EVs in the subsample simulation the resulting charging profiles approach the EV fleet population curve, both in the shape and the period in the peak hours, where the probability of all the EVs being at home and connected to the grid, is reduced. Though, for 20 EVs in a sample which all charge with 3.7kW, there is still a need to reserve a CP for all 20 vehicles in the peak hour between 17:00 and 18:00.

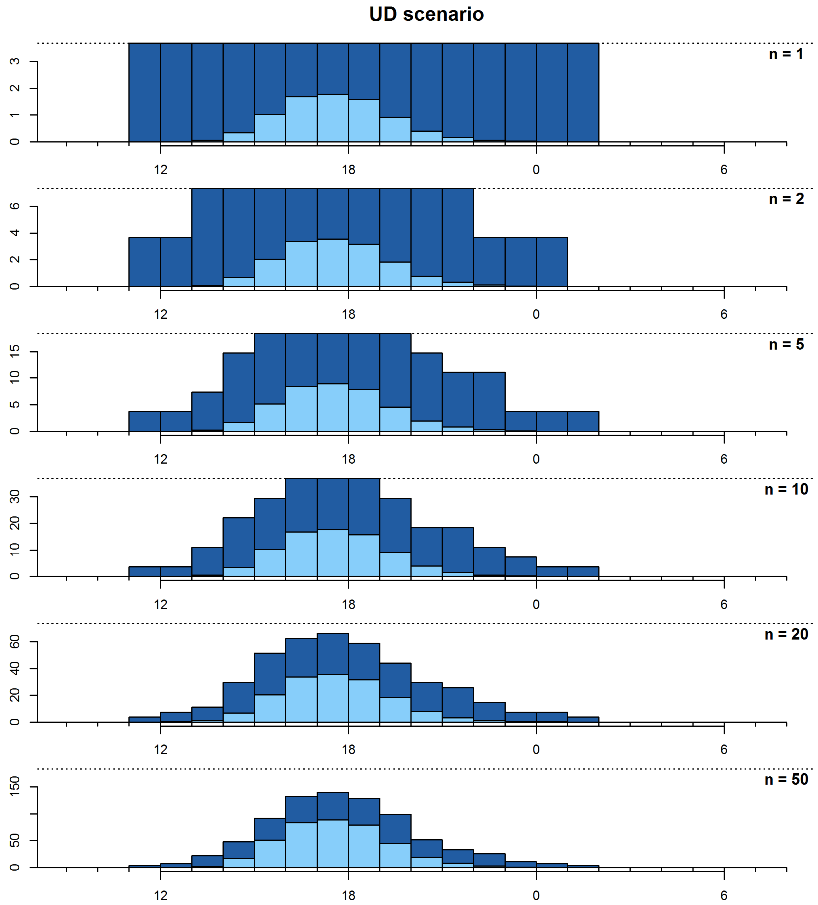

Figure 6.2.3 User Dependent charging profiles for charging power of 3.7kW).

Scenario 2 – Timer Based

By avoiding consumption due to the EVs in the peak hours, all EV charging is delayed several hours, or to a point in time where the consumption is reducing, following the peak hours between 17:00 and 20:00. Delaying the charging for the subsamples in the simulation study results in the charging profiles presented in Figure 5.2.4. It is not surprising that the subsample simulation and corresponding population average care equal charging power, since at 20:00 all, or almost all, of the EV fleet population has returned home. Thus, when the charging is initiated at 20:00, all vehicles in the sample size are connected to the grid. However, for the subsample simulation it is the charging time that is of great interest. The rapid completion of charging of the population average is not consistent with the total energy consumption of the EVs in the subsample. On the other hand, the subsample approach provides the correct energy consumption to the EVs of the sampling group.

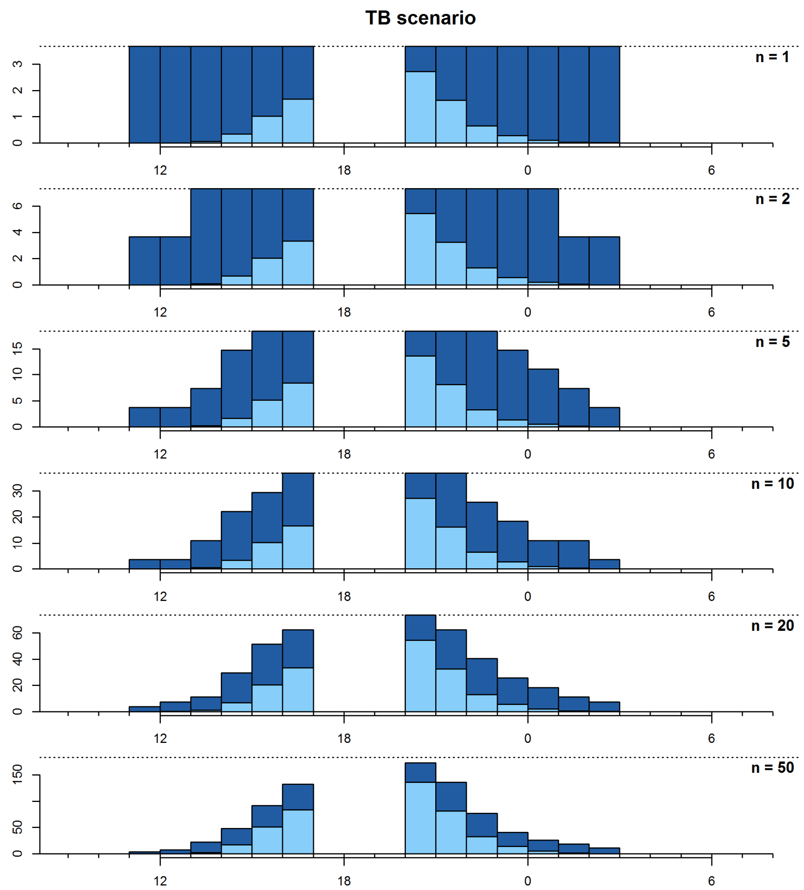

Figure 6.2.4 Time Based charging profiles for charging power of 16A – 3.7kW).

Scenario 3 – Load Dependent

The third scenario considered is a strategy that depends on the existing load of the grid under consideration. The load is determined by use of the subsample method described in section 6.2.3 for the actual number of customers connected to the specific grid. Figure 6.2.5 below shows the load of 50 customers.

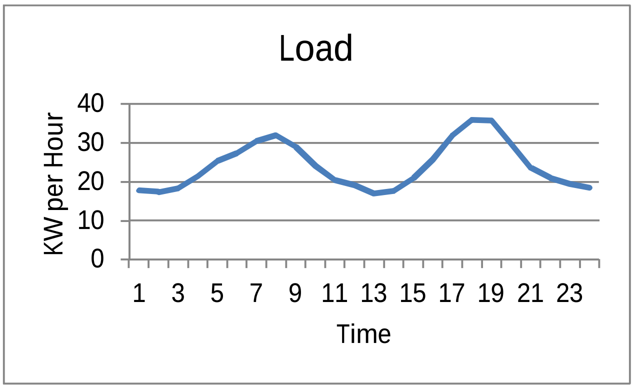

Figure 6.2.5 Italian load profile for 50 customers

For the simulation study of a specific grid, e.g. an Italian grid with 50 customers connected the load dependent EV charging profile is generated on basis of the load profile in Figure 6.2.5. Secondly, the total energy consumption of EVs, with a sample size equal to the actual number of customers, e.g. 50, is calculated. As shown on Figure 6.2.6 the total energy consumption of 50 EVs is 425.6 kWh per day. The required energy consumption for charging EVs is added to the required energy consumption of the traditional load per day, which gives the total required demand of energy per day. The total demand of energy is spread evenly throughout the day. By subtracting the energy consumption of the traditional load per hour, the load dependent CP of 50 EVs is derived, which is shown on Figure 6.2.6. Finally the CP is normalized to one EV. This approach is not realistic, since each EV does not have the same CP, which indicates that the load dependent strategy should be approached by an online-like control, where a strategy for the CMS is determined by compromising between the charging parameters (Table 3.1.2) and the grid component parameters (Table 3.1.4). However, this is out of the scope of this study, where the load dependent scenario is meant to demonstrate a more realistic shape of CPs, as if they were controllable depending on the actual load of the low voltage grid.

Figure 6.2.6shows the results from the subsample simulation study for the 16A – 3.7kW charging profiles for all the EVs in the sample size. The plots show clearly how the CPs are very similar for different numbers of EVs.

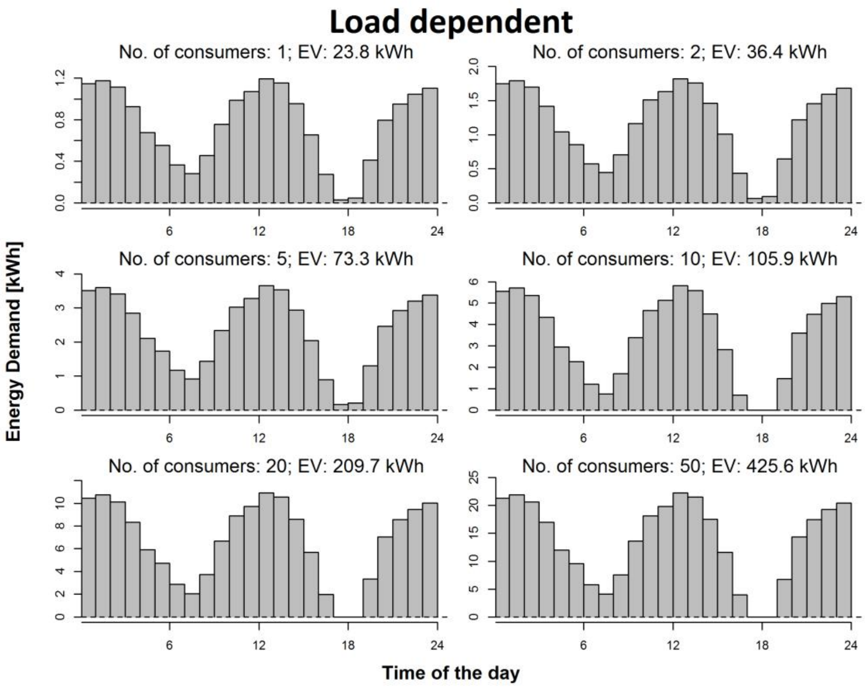

Figure 6.2.6 Load dependent charging profiles for charging power of 16A – 3.7kW

6.2.3 Subsampling of load profiles

The subsampling approach, as it is applied in this simulation study, can be applied for simulations of other profiles than the EVs, such as the electricity consumption (S_c in Table 3.1.4), or the load on the low voltage grid. Similar to the evolution of the subsampled CPs for an increasing number of EVs (Figure 5.2.2), the increasing number of households on the low voltage grid has the same features, as displayed in Figure 5.2.6. For demonstrating the load profiles, a population consisting of residential houses is exploited, but the figure shows the clear difference between the population average of the load (light shaded area) and the subsampled load profiles (dark shaded area). Also very obvious from Figure 5.2.6, for very few households the surface of the subsampled load profile is not as smooth as the population average, but follows a similar curvature where the minimal load is during the night hours and the peak load is close to 17:00. As the number of households increases on the low voltage grid, sampled load profile approaches the population profile, though proportionally faster than the one observed for the EV population in Figure 5.2.2. Moreover, the shape of the sampled load profile is smoothening out in relation to the increasing number of household in the sample.

This demonstration shows the importance of subsampling also the load profiles to obtain a more realistic scenario on the low voltage grid. To obtain an actual load profile, where the EV scenarios are added to the traditional household, one has to account for the variation in both the EV fleet profile and the load profile. By adding the two profiles to attain a scenario for very few consumers on the low voltage grid can easily result in a composed load profile that exceeds all limits, especially if the User Dependent charging scenario is applied since it is a combination of profiles with peak in the same hours of the day (between 16:00 and 19:00). Hence, the subsampled load profiles provide more correct approach to the aggregated load profiles on the low voltage grid. However, this addition of the load profile is only meant as a demonstration and is, therefore, not investigated further in this simulation study.

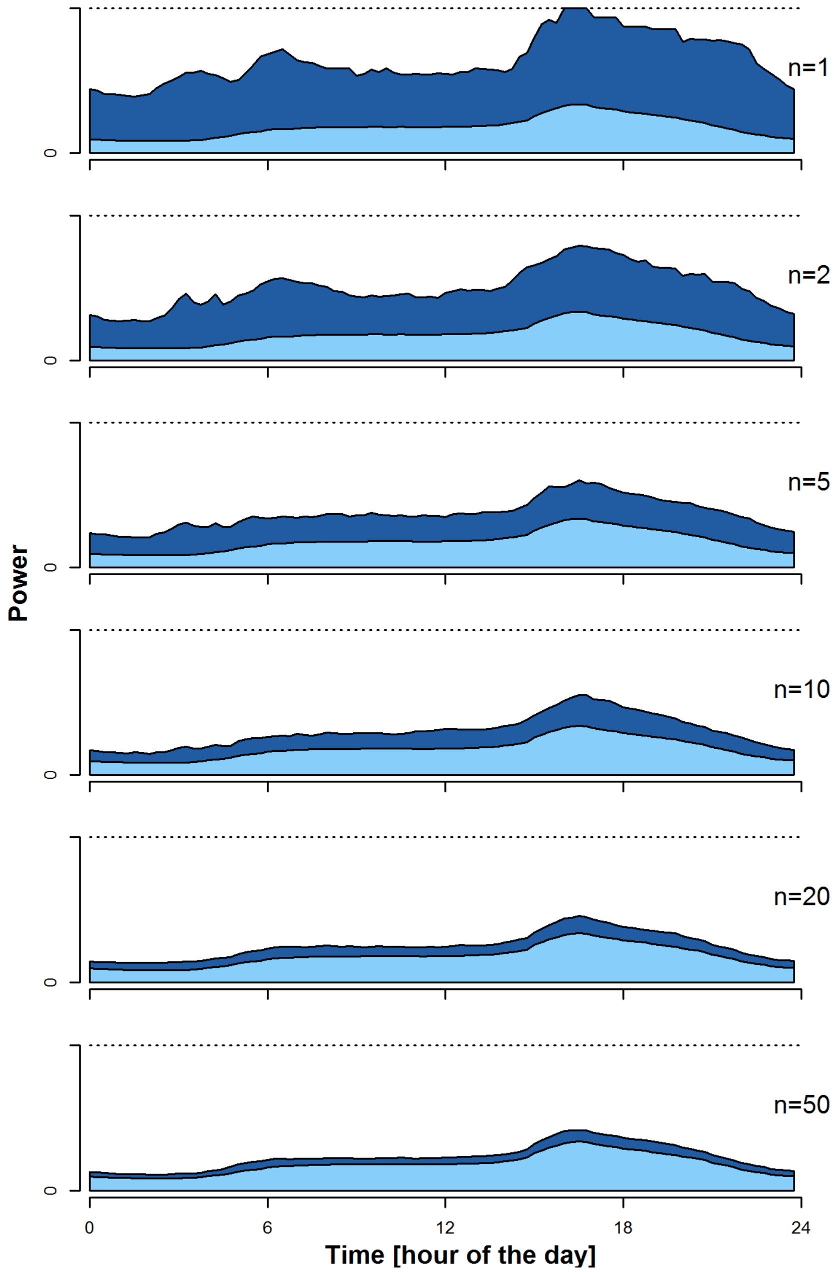

Figure 6.2.7 Comparison between the subsampled load profile (dark shaded area) and the population average for the load (light shaded area), for n number of households on the grid. Top-down shows the subsampled load evolves from being significantly different for a single household, to a subsampled load that is very similar and very close to the population average for 50 households.

6.2.4 Concluding remarks

The simulation study shows that using the population average to obtain a CP for the energy consumption on the low voltage grid can easily provide very unrealistic scenarios, which are severely underestimated. More realistic approach is to aggregate a number of subsamples to capture the actual demand of each EV in the sample size, which, consequent to the number of EVs with connectivity to the grid, renders a probable CP that accounts for the grid impact of each EV. This individual EV impact is reduced as the EVs that are connected to the low voltage grid, along with that the shape of the probable CPs that for very few EVs is very stepwise, but with increasing number of vehicles connected these steps dissolve and the probable CP approaches the population average CP.

Another topic to highlight from the simulation study is that the three different charging scenarios illustrate the potentials for the CP flexibility, since the CMS will be able to exploit all possible outcomes. Hence, the management strategies should involve several scenarios for the charging profiles, where the optimum provides a compromise between the grid and the user.

On the low voltage grid the sampling approach can, and should also be applied to obtain load profiles for the traditional energy consumption. The included demonstration clarifies the importance of accounting for subsampled charging and load profiles. Subsequently, the aggregated subsampled profiles are utilized for decision making in the CMS for the EVs connected to the grid.

6.3 *Annex 3 - Survey regarding parameters for electric cars affecting electric network*

This survey is directed at Grid Company personal in the net planning department, for low voltage grids. The low voltage grid is typically not supervised as it is the case with higher levels of voltage e.g. 132kV and is dimensioned from algorithms for expected load in the radials. The nearest real measurement of current and voltage on the grid is often at the 50(60) kV /10 kV transformer station which feeds the radial.

The development in our society tends toward a larger consumption of electricity. Each household have the prospect of heating with a heat pump, which uses a substantial amount of electricity and runs almost constantly during winter time. The future may also bring electric cars (EVs) in each household and small solar power cells have penetrated the market and are expanding. In the long run this changes the current method of dimensioning the low voltage grid. As the development takes effect the network should be exploited closer to its limits and parts of it will need reinforcement.

Previous projects regarding electric vehicles such as G4V, EDISON and MERGE have discarded the possibility of constructing general rules for the reinforcement of low voltage grids. In task T4.3 in project Green eMotion the investigation concerns which parameters -e.g. number of EVs, charging power etc. - are relevant when assessing the impact EVs have on low voltage grids. Recommendation for new functionality of grid planning tools will be based on this investigation. The project GeM will focus on electric cars but the results will comply for an evaluation of other components as well.

Status for new household elements

The grid already contains an amount of solar cells, EVs and heat pumps though not jet in every household. In Denmark solar cells must be registered giving the grid company the knowledge of their number and placement but heat pumps and electric vehicles just show up as ordinary consumption. At peak load time this increase puts pressure on the capacity of the grid, even for a small amount, however, as EV penetration rises even the general load time might experience capacity shortage.

This problem has not gone unnoticed and mitigation measures are already under construction for the negative impact of the load increase e.g. the EV charger can be time controlled to place its load in the night time which has a low general load. All parameters are of interest in this investigation, even those with a mitigation measure. The purpose with this survey is to have a point of view from the grid company as to which parameters should be evaluated in order to analyze the effect EVs have on low voltage grids.

<table>
<tr><td colspan="2">Electric cars</td></tr>
<tr><td colspan="2">Background: The questions in this category concern the electric car and its properties in case they might affect the grid, or the way a grid is maintained or planned. An electric car is a vehicle which has electricity as it main source of energy, thus the need for power when charging the car depends on the use of the EV.</td></tr>
<tr><td>How do you asses the need to know the number of EVs in the company grid?
Do you need the actual place of the component, thus the registration should be mandatory?</td><td>Answer</td></tr>
<tr><td>Will it suffice to know the number for each radial and so obtain the knowledge for instance from the vendor, voluntary registration or by request?
Can registration be avoided and the number estimated by calculation?</td><td>Answer</td></tr>
<tr><td>How do you assess the necessity of knowing the type of electric vehicle and possibly other major consumption?
Must every household register when purchasing and inform the type of electric car and what type of heat pump they use?
Is actual registration necessary or can it be done e.g. by calculations?</td><td>Answer</td></tr>
</table>

<table>
<tr><td>Are there other parameters of the electric car that you believe are important to maintain the low voltage grid and still exploit it closer to its limits?</td><td>Answer</td></tr>
<tr><td colspan="2">Charging stand, the household charger</td></tr>
<tr><td colspan="2">Background: Today, electric cars are often charged directly e.g. no charger to control the charging. But charging stands are also used both urbanely and by households. The charger enables control of the charging procedure by e.g. time setting or other parameters and some include an electricity meter for billing purposes. Furthermore, the charging power depends on the charger.</td></tr>
<tr><td>At selected locations fast-chargers are constructed which use as much as 32A by multiple phases.
Do you assess the grid company must register each fast-charger e.g. the constructor must report?
• Instead of registering the fast-chargers should the company be involved when choosing its placement, or perhaps both?
• Do you have other concerns regarding fast-chargers?</td><td>Answer</td></tr>
<tr><td>Charging power is currently often around 2,3kW and in one phase.
How do you assess the impact charging power has on the grid when including the increase in EVs?
• Must the future chargers be three phase balanced also in all households (for symmetry)?
• Must each charger have its own meter?
• Must the grid company register the type of charger for each radial to know the maximum power?</td><td>Answer</td></tr>
</table>

• Should the charger have built-in functionality such as turning off depending on voltage or frequency? • Should the charger have built-in strategies? • Do you see a demand for being able to control groups of chargers i.e. by a third person (perhaps the vendor) in order to reach a very high number of electric cars in the grid?	Answer
Are there other parameters of the charger that you believe are important to maintain the low voltage grid and still exploit it closer to its limits?	Answer
Type of consumer, new consumer pattern	
Background: The new components alter the ordinary household consumer which often is a standard client. They usually have a fairly predictable consumption through the day and show stability, especially accumulated. But just one new component, or perhaps two or three will change the consumption and hence the load in the low voltage grid. Since the number of this type of consumer is/ will be large, their behavior has a great effect.	
Do you assess that it will be necessary to know the new consumption in order to plan the low voltage grid? • Should each consumer be registered and then be described by a formula? • Can the new consumer data be based upon measurements already collected, and can the new consumers be described as a new type?	Answer

<table>
<tr><td>

- Is it possible to use a projection model and thus use calculations to avoid a registry?
- Will the new type of consumption be cause for high uncertainty regarding the state of the low voltage grid and will wide use of monitoring be needed?

</td><td>Answer</td></tr>
<tr><td>Are there other parameters regarding the change in consumption that you believe are important to maintain the low voltage grid and still exploit it closer to its limits?</td><td>Answer</td></tr>
<tr><td colspan="2">Supervision and measurements</td></tr>
<tr><td colspan="2">Background: There is constant monitoring at the higher voltage levels, but at low voltages a meter on every transformer or cable would be a costly affair. Therefore, calculations and slight direct supervision of components are used. Fuses protect the components but it is expensive should they come in use. A better way to protect the elements could be monitoring and proper response.</td></tr>
<tr><td>In the future, do you see a demand for increased monitoring and measurements at low voltage?

- Should smaller transformers e.g. have heat monitoring or should currents in cables be measured?
- Should a method of choosing which area to monitor be developed possibly based on presence of older components, substantial increase in consumption etc?

</td><td>Answer</td></tr>
</table>

• Do you foresee substantial costs for reinforcement in the future or could a better exploit of the capacity of the grid be sufficient?	Answer
Are there other demands for monitoring and measurements which you believe are important to maintain the low voltage grid and still exploit it closer to its limits?	Answer
Network types and components	
Back ground: Networks and network components are very different depending on location and type of network such as whether it is in the city, rural, has industrial customers and the like. These factors are used when dimensioning components but they have a long lifespan and circumstances can change during their lifetime	
How do you assess the type of network impacts the way you plan and reinforce the grid? • Are there types of grids where the new consumers will not have any significant impact? • Are there types of grids which are vulnerable and will lead to costs for either monitoring or reinforcement?	Answer

• Should future planning tools take into account the type of grid?	Answer
Grid planning tools	
Background: In order to exploit a grid closer to its limits the performance of the grid should be well-known. Also, how it should perform in the future. This planning can be supported by grid planning tools such as calculations, simulations etc. Currently these are rarely used on low voltage levels but with the new demand to the grid performance it may be a necessity.	
Do you assess that in the future it becomes necessary to use tools to plan low voltage network? • Must they take into account the growing development of new components, electric cars, solar panels etc.? • Should the tool be able to take input like consumption, or take into account the age of the components?	Answer
Are there other parameters of future grid planning tools that you believe are important to maintain the low voltage grid and still exploit it closer to its limits?	Answer

Any other comments or suggestion?

Thank you very much for your time!

Grid company	
Answered by	
Date and place	