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Electric Vehicle Charging Systems and Their Impact on Building Internal Electricity Distribution

School of Electrical Engineering

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ABSTRACT OF THE
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The number of electric vehicles (EVs) is expected to grow strongly in the next few years. The charging of electric vehicles could cause significant impacts on building electricity distribution network and therefore required design.

Still, only little research has focused on the impacts on building electricity distribution. The main goal of this thesis is to investigate how large or semi-large EV charging systems affect the building electric infrastructure. Additionally, this thesis aims to determine the required modifications to design work.

The data used in this thesis is based on a literature review and three case studies of building types parking building, hotel and shopping center.

The results indicate that the large scale electric vehicle charging systems will impact on the network power quality, economical operation and designing.

In conclusion, electrical measurement data combined with data of other sources like occupancy information and car types should be analyzed to verify load profiles to create parametrized functions with aim to evaluate load needs at early stage of design. Further standardization of peak load evaluations is recommended.

Keywords: Electric vehicle, EV charging, load management, electric network, building

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Sähköautojen määrän uskotaan kasvavan voimakkaasti lähivuosina. Sähköautojen yleistyminen aiheuttaisi merkittäviä muutoksia sähkönjakeluun ja näin ollen myös suunnitteluun. Siitä huolimatta yksittäisten suurien latausjärjestelmien vaikutuksia sähkönjakeluun on tutkittu vain vähän.
Tässä työssä tutkitaan simulointien avulla suurien ja keskisuurien latausjärjestelmien vaikutusta sähkönjakeluun ja suunnitteluun. Työssä keskitytään tutkimaan parkkihallin, hotellin sekä kauppakeskuksen sähköautojen latausjärjestelmän vaikutuksia kohteen sähkönjakeluun.
Tulosten perusteella yksittäisillä suurilla latausjärjestelmillä voi olla huomattavia vaikutuksia sähkönlaatuun, kustannuksiin ja suunnitteluun. Latausprofiilit edellyttävät kuitenkin vielä lisätutkimuksia. Tämä vaatii lisää mittaustietoja sähköautoista ja niihin liittyvistä asennuksista.

Avainsanat: Sähköauto, sähköautojen lataus, kuormanhallinta, sähköverkko, kiinteistö

Contents

Abbreviations

Abbreviations

AC	Alternative current
ACEA	European Automobile Manufacturers' Association
CAPEX	CAPital EXpenditure
CO_2	Carbon dioxide
DC	Direct power
EN	European Standard
EU	European Union
EV	Electric Vehicle
GV	Gasoline Vehicle
ICE	Internal Combustion Engine
IEC	International Electrotechnical Commission
LV	Low Voltage
MDB	Main Distribution Board
MV	Medium Voltage
NEDC	New European Driving Cycle
OCPP	Open Charge Point Protocol
OPEX	OPerating EXpenditure
RCD	Residual Current Device
PHEV	Plug-in Hybrid Electric Vehicle
PLC	Programmable Logic Controller
PWM	Pulse-Width Modulation
SAE	Society of Automotive Engineers
SFS	Finnish Standards Association
THD	Total Harmonic Distortion
V2G	Vehicle-to-Grid

1 Introduction

The number of electric vehicles (EVs) is expected to grow strongly in the next few years. Increasing the charging of electric vehicles could cause significant impacts on building electricity distribution network and therefore engineering practices. (VTT, 2010)

An electric car is an old invention. The first EVs were built by the end of the 19th century in France and in the United Kingdom. There has been a several periods of interest in 1970s, 1980s, 1990s, 2000s and 2010s. It is forecasted that in the 2010s the EVs will make break through and will become available for consumers at large scale. One reason could be that in the recent years the world has come more aware of the climate change. (Ehsani et al., 2010), (Transportation Research Board and National Research Council, 2015)

The European Union legislation sets mandatory emission reduction targets for new cars. The mandatory requires that the new car in the EU does not emit more than an average of 130 grams of CO_2 per kilometer by 2015. Emission reduction limits drop to 95 grams of CO_2 per kilometer by 2021. The purpose of emission reductions and tax policy is to improve the fuel economy of cars on the European market. This causes the pressure of the car manufacturers to develop EVs. (The Ministry of the Environment, Finland, 2016)

Electric vehicles are still facing many challenges. The major obstacle preventing EVs from becoming more commonly used is the limited driving range, which is generally between 50 and 500 km. In addition, the charging time is long, ranging from 20 minutes to 10 hours to reach a charge level of 80 percent. Therefore, if EVs are becoming increasingly more common, the number of charging stations must grow substantially, especially in places where people come with cars to spend time. Such as places are for example work places, shopping centers and hotels. Still, the charging time would need to be reduced to more reasonable level. Parking facilities and shopping centers are potential places for large scale charging systems. This would mean that several charging stations are connected to building internal distribution instead of multiple utility connected stations. Such systems would require larger capacity in internal distribution network than normally needed of a building type. For example, parking facilities are nowadays designed for much less capacity.

Several studies have been conducted on the impacts of charging electric vehicles on utility distribution network by running simulations. Many studies have focused on the impacts of EV charging on the transformers, and MV (medium voltage) and LV (low voltage) utility networks.

VTT (2010) forecasted the different scenarios for the growth of EVs in Finland. Additionally, their study also focused on the potential the impacts on the electricity distribution on a large scale. Furthermore, a number of theses in Finland have been made regarding the impacts of EVs on the utility network. Alihäivälä (2012) investigated the impact of charging on the utility transformers and the grid. Ünsal Yurdakul (2013) studied the effects of EV charging on the LV utility network. Lehtinen (2010) focused on invoicing and metering as a part of EV charging as well as on the impact of EV charging on the suburban network.

Furthermore, there is a number of technical articles concerning on the effect of the power quality. Kütt et al. (2014b) reported that the harmonics likely do not reach critical values in case of EV charging. Further, impact on the quality of electricity were studied by Kütt et al. (2014a), Ma et al. (2015) and Beaude et al. (2015). Together, these studies indicate that the large scale EV charging may impact on the network power quality, economical operation and designing.

Much research has focused on impacts on electricity distribution at suburban level. However, little research has focused on impact on building internal electricity distribution. The purpose of this thesis is to investigate how large (up to 100 charging points) or semi-large (5-30 charging points) EV charging systems affect the building electric infrastructure. There are three primary aims of this study: 1. To provide a set of typical design documents of EV charging system 2. To identify the impacts on the power calculations 3. To settle the typical design structures of EV charging systems.

The research data in this thesis is drawn from a literature review of related work as well as three case studies of building types: parking building, hotel and shopping center.

This thesis consists of the following chapters. Chapter 1 gives an overview of the basics of electric vehicle. Chapter 2 is concerned with parts of the EV charging system. Chapter 3 presents the main issues of design works and focus on the three case studies. Chapter 4 analyses the results of this study. Chapter 5 concludes an summarizes this study.

1.1 Electric vehicle technology

Electric vehicles are vehicles, which are powered by electricity. There are in generally one or more electric motors for example, one motor per wheel. Such as defined in standard " any vehicle propelled by an electric motor drawing current from a rechargeable storage battery or from other portable energy storage devices (rechargeable, using energy from a source off the vehicle such as a residential or public electric service), which is manufactured primarily for use on public streets, roads or highways " (IEC 61851, 2010)

The field of electric vehicles includes all vehicle applications which are use an electricity for power train. In this thesis the electric vehicles (EV) are referred to as electric cars. The EV is propelled by an electric motor drawing current from an electric battery. The electric vehicle is like an any other fossil fuel car excluding a method of power system. The electric vehicle consist of an electric battery for energy storage, controller and an electric motor or motors. (Ehsani et al., 2010)

Depending on the size and performance of motor, the total capacity ranges are between 15 and 200 kW. For example, Tesla Model S has an electric motor per each tire and the total capacity of car is over 500 kW. Conversely, the power capacity of small EVs such as the kei-car class is around 40 kW. As seen in table 1 the battery capacities and the ranges are quire small excluding Tesla. The part of manufacturers announces the range of EV as the NEDC (New European Driving Cycle). NEDC is a standardized driving cycle. NEDC supposed to present an average usage of car in

Europe. However, NEDC values are only theoretical since the test procedures are made laboratory at a roller test bench.

Table 1: Technical specs of some EVs. Tesla Motors (2016), Volkswagen (2015), Daimler (2015)

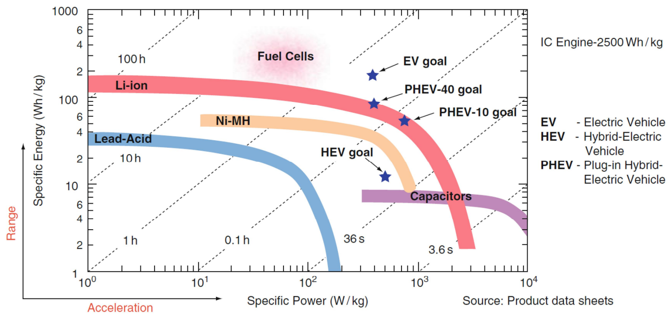
	Tesla Model S P90P	Volkswagen e-Golf	Mercedes Benz B Electric Drive
Elecric motor -Power [kW] -Torque [Nm]	515 967	85 270	132 340
Capacity of batteries [kWh]	90	24,2	28
Range [km]	509 (NEDC)	190 (NEDC)	140

The batteries have significant share of the total weight of the car due to a small specific energy of batteries. The specific energy of batteries is only about 0,18 kWh/kg. In contrast, the specific energy of gasoline is about 11,9 kWh/kg. However, the efficiency of gasoline ICE (internal combustion engine) is about 25 percent conversely, the efficiency of EVs is up to 85...90 percent. For example, a gasoline vehicle (GV) with a 60 kg tank get 178 kWh mechanical energy out. The same amount of mechanical energy in the EV by batteries weight 1100 kg. This is illustrated roughly as follows.

$$GV \Rightarrow 60kg\ x\ 11,9\frac{kWh}{kg}\ x\ 0,25 = 178kWh$$

$$EV \Rightarrow 178kWh/0,18\frac{kWh}{kg}\ /0,9 = 1100kg$$

Lithium batteries have a very high energy density comparing to other battery types. The power density of a lithium battery is about 100-200 Wh/kg whereas, the power density of a lead-acid battery is only 30-50 Wh/kg. As shown in Figure 1 the lithium battery have a good power density comparing to others.



Source: Product data sheets

Figure 1: Energy ranges of batteries

The battery packs are the most costly part of the EV. The car manufacturers generally will not report what they are paying for their batteries. However, a some information is available mainly regarding the replacement batteries. For example, replacement batteries to Tesla EVs costs from $ 8 000 (40 kWh) up to $ 12 000 (85 kWh)(Tesla Motors, 2012). This means roughly $ 200 per kWh. According to a article in February 2016 by Bloomberg, battery prices would be below $ 120 per kWh by 2030.(Bloomberg New Energy Finance, 2016)

1.2 Current status of electric transportation in Finland and Europe

Finland is still at early path of gaining customer acceptance and popularity towards EVs. The amount of EVs in Finland in 2015 was only 500 pcs. In contrast, in Norway the amount of EVs in 2015 was as much as 80 000 pcs. It is speculated that reasons of that EVs have not become more common in Finland are such as expensive purchase price and general public opinion. (VTT, 2010)

In 2015, more than 140 000 EVs were registered in the EU, up 100 percent compared to 2014. EVs are very popular in the Norway and the Netherlands (Table 2).

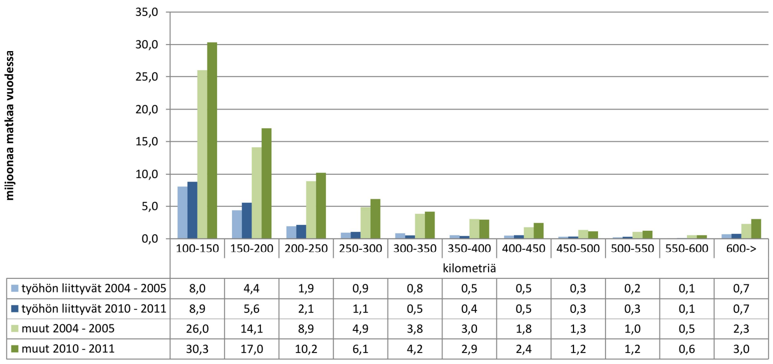
Table 2: EV registeration in 2015 of total passenger car registrations (ACEA, 2016)

Country	**Share**
Finland	0,6%
Germany	0,7%
UK	1,1%
France	1,1%
Sweden	2,5%
Netherlands	9,7%
Norway	22,3%

The EV policy have significant impact on that how attractive customers see the EVs. Thus, the basic components of EV policy in Finland 2015 are following

- No specific incentives for EVs
- Tax favours for car with low CO_2 emissions
- Innovation supports (TEKES). (Munther, 2015)

According to the national passenger transport survey, the average distance of whole day trip is about 40 km. Additionally, the amount of shopping and personal business trips has increased while the amount of visits, trips to summer cottage and other leisure trips has decreased. Figure 2 shows an overview of long distance trips in Finland. (Finnish Transport Agency, 2012)



	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600	600->
työhön liittyvät 2004 - 2005	8,0	4,4	1,9	0,9	0,8	0,5	0,5	0,3	0,2	0,1	0,7
työhön liittyvät 2010 - 2011	8,9	5,6	2,1	1,1	0,5	0,4	0,5	0,3	0,3	0,1	0,7
muut 2004 - 2005	26,0	14,1	8,9	4,9	3,8	3,0	1,8	1,3	1,0	0,5	2,3
muut 2010 - 2011	30,3	17,0	10,2	6,1	4,2	2,9	2,4	1,2	1,2	0,6	3,0

Figure 2: Long distance trips in Finland (Finnish Transport Agency, 2012)

1.3 Prospects of electric transportation in Finland and Europe

The biggest argument against EVs has been a limited battery range. However, as shown in Table 1 and in Figure 2 average of the trips are shorter than the ranges of EVs. Furthermore, Needell et al. (2016) has reported that nearly 90 percent of the personal vehicle trips could be replaced by an EVs.

VTT study ”Scenarios of large-scale deployment of electric vehicles and their power system impacts” presents EV deployment scenarios from literature as well as two possible scenarios for Finland. Thus, these three scenarios are basic scenario, fast scenario and slow scenario. Even in the ”slow scenario” the amount of EV registration in 2020 is 5 percent and in 2030 is 10 percent of the total passenger car registrations (Table 3). (VTT, 2010)

Table 3: Electric vehicle deployment scenarios (VTT, 2010)

	Share of new cars, %				**Cumulative amount, pcs**			
	2020		**2030**		**2020**		**2030**	
	EV	**PHEV**	**EV**	**PHEV**	**EV**	**PHEV**	**EV**	**PHEV**
Basic scenario	3	10	20	50	13 000	66 000	160 000	480 000
Fast scenario	6	40	40	60	26 000	190 000	450 000	960 000
Slow scenario	2	5	10	20	12 000	38 000	92 000	207 000

EV= Electric Vehicle
PHEV= Plug-in Hybrid Electric Vehicle

The target of government platform concerning greenhouse gas is to cut 40 percent in greenhouse gas emissions compared to 1990 level. One legislative action is increase cost-efficiently the technology of EV. The government platform also aims to decrease the use of crude oil by 40 per cent compared to 1990 level. (The Ministry of the Environment, Finland, 2016), (Helsingin Sanomat, 2015), (European Union, 2016)

2 Electric vehicle charging system

2.1 Technology overview

The principal of EV AC charging is shown in Figure 3. The EV is connected to the electricity distribution through the charging station. Necessary control and protection equipment are installed in the building distribution system. The charger is located in the vehicle. The charging station limits the charging power by communicating with the EV.

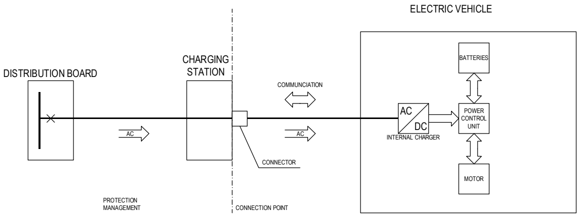


Figure 3: Simplified principal of EV AC charging (mode 3)

The basic idea of DC charging (Figure 4) is the same as AC charging except that the charger is located in the charging station. This enables higher charging power because the dimensions and the weight of charger do not limit the performance of EV.

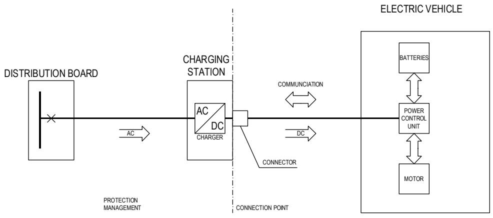


Figure 4: Simplified principal of EV DC charging (mode 4)

In the standard IEC 61851 (Electric vehicle conductive charging system) charging methods are divided in four categories. These four categories are divided into slow and fast charging. Mode 1 and mode 2 are for home charging and mode 3 and mode 4 are for commercial and public charging. In addition to these four categories, in July 2015 was published wireless charging standard IEC 61980. IEC 61980 applies to the equipment for the wireless transfer to electric power from the supply network to electric road vehicles.(IEC 61851, 2010), (IEC 61980, 2015)

Standard IEC 62196 is applicable to electrical connectors for EVs for in use of charging modes 3 and 4 (Figure 5). Based on historical causes there are three competing plug types for the mode 3 charging and two plug types for the mode 4 charging. Type 1 is a single-phase connector for mode 3 according to SAE J1772, which is North American standard for electrical connectors for EVs. Type 1 connector, known colloquially as the ”Yazaki”, based on name of the original manufacturer of connector. Connector is commonly use on EVs of North America and Japan. Type 2 is a three-phase connector for mode 3 according to VDE-AR-E 2623-2-2, which is German standard. Commonly called name of type 2 connector is ”Mennekes”. Type 2 connector is the most common plug type in Europe. Finnish standard association recommended to use type 2 connectors to all new installations. (SESKO ry, 2015)

Figure 5: IEC 62196 plug types (Mennekes, 2013)

Type 3 is a three-phase connector for mode 3 which has developed EV Plug Alliance by electrical companies in France and Italy (Schneider Electric and Scame). Commonly name of type 3 connector is ”Scame”. Type 3 connectors are further divided into three subcategories 3A, 3B and 3C. Type 3 connectors are mainly used in France.

According to the installation standards (IEC 60364 series) each connection points shall be protected by a individual RCD, so if used charging station with two socket, there shall be two RCD in charging station or in supplying distribution board. Thus, if RCDs are in supplying distribution board there shall be two different power supplies (two cables) for one charging station. When using three-phase supply and features of the load is not known, RCDs shall be type B. This means all public charging stations in practice. RCD type B is like type A but also suitable for pulsating direct current.

Each connection points shall be protected for overcurrent. Outdoor charging stations shall be protected for external influences, IP class at least IP44. A minimum degree of protection shall be at least IK07 (IK08 in Finland), if charging station is installed in the public places. Insulation monitoring system shall be provided if IT earthing system is used. (IEC 60364, 2015)

2.2 Charging station

The charging station is in practice a fixed 3-phase socket outlet with communication modules (mode 3). Charging stations are mainly floor-standing or wall mounted with a one or two outlets. Optional accessories are for example fixed cables, RFID badges and communication modules.

Charging stations are usually equipped without fixed charging cables and, furthermore in some countries fixed cables are forbidden like in Norway. However, fixed charging cables are used for some special applications such as closed areas e.g., factories. NEK 400 (2014)

RFID is commonly used for a user identification. Other identification methods can be e.g., a mobile phone (application), a PIN code, a voucher system or a remote control. The remote control can be used for example, when the visitor connect the EV to the charging station and then reception activates the charging.

Based on the standard IEC 61851, following functions shall be provided by the EV and charging station

- Verification the vehicle is properly connected
- Protective earth conductor continuity checking
- Energization of the system
- De-energization of the system (IEC 61851, 2010)

Additionally, following functions are optional and should be provided by the EV and charging station

- Selection of charging rate
- Determination of ventilation requirements of the charging area
- Detection and adjustment of the real time available load current of the supply equipment
- Retaining and releasing of the coupling
- Control of bi-directional power flow to and from the vehicle (IEC 61851, 2010)

2.3 Charging modes

The charging modes is defined in IEC 62196. According to the standards there are referred to as charging modes 1, 2, 3 and 4. Mode 1 is for slow charging from a household-type socket (schuko). Mode 1 charging method is mainly used to supply light electric vehicles, for example an electric two wheeler. The rated current is limited to 16 A and voltage is limited to 250 V single-phase and 480 V three-phase. Based on these limitations the maximum charging power is 3,7 kW at single-phase and 11 kW at three-phase.

Mode 2 is for slow charging from a household-type socket with a special cable with protection and control devices. Mode 2 charging method is used to charge EVs temporary or limited extent. The in-cable control box includes the system of personnel protection against electric shock as such as RCD and control pilot function which limit current. A household-type socket can be used if long time charging current is limited to enough (up to 8 A). Nevertheless, household-type socket is rated to 16 A, but it is not intended for long-time loading. The current limitation of charging cable based on PWM system. PWM module conveys the maximum possible charging current to the vehicle. Rated current is limited to 32 A and voltage is limited to 250 V single-phase and 480 V three phase. Based on these limitations maximum charging power is 12 kW at single-phase load and 22 kW at three-phase load. (IEC 60364, 2015) (IEC 60364, 2012)

Mode 3 is slow or fast charging from specified EV socket. Mode 3 is especially designed for EVs. According to IEC 61851-1 mode 3 connectors have control and signal pins on both ends of the cable. Control unit limit the current and also charging station is non-live if no EV connected. This allows the higher currents up to 250 A single- and three-phase loads. Based on these limitations maximum charging power is 175 kW at single-phase and 300 kW at three-phase.

Mode 4 aka DC charging is fast charging from specified EV socket. Battery charger is located in the charging station. Power supply from charging station to vehicles implements D.C. External battery charger allows higher charging powers.

2.4 Norms, standards and guidelines

The most important norms and standards concerning the design of EV charging are

- National legislation
- IEC 60364 standard series (SFS 6000) and especially parts
    - IEC 60364-7-722: Supplies for electric vehicles and
    - IEC 60364-8-813: Selection and erection of plugs and socket outlets
- IEC 61439-8: Low-voltage switchgear and controlgear assemblies
- Low voltage directive, EU (LVD)
- Electromagnetic compatibility, EU (EMC)
- EN 61851 standard series and especially part
    - EN 61851-1:Electric vehicle conductive charging system - Part 1: General requirements
- Open Charge Point Protocol OCPP
- Relevant standards for devices

Standards define the level of protection and some other refinements. Instead, standard not specified how the system shall be design such as the structure of charging system, the functions of back-end system etc. More of these are discussed in the following sections.

2.5 Structure of charging system

Charging systems have so far been small in Finland. Typically, from 1 to 5 charging stations per site. Therefore, the structure of charging system is not very relevant as a small systems. However, when the amount of charging stations gets greater, more attention to the structure of EV charging system will be needed due to functionality, maintenance and costs.

Small EV charging installations can be installed at the same distribution with other loads. Alternatively, unnecessary large capacity reservations for the EV charging cause unnecessary investment and operating costs For example, a bigger main distribution board and a bigger utility connection increase the investment and the operational costs.

In these cases, at early project stage it may be practical to reserve only space for the dedicated distribution for EV charging, including transformer, distribution boards and charging stations. Thus, there will are not be unnecessary capacity reservations in the normal services. The simplified structure of a small charging system is presented in Figure 6.

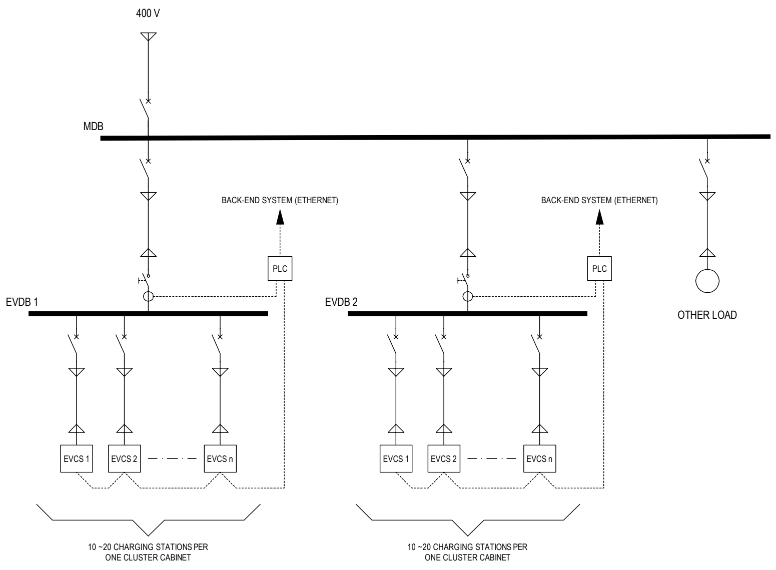


Figure 6: Small charging system

A larger EV charging systems should be reserved to a individual section of distribution. This way, metering, load management and operating are easier to handle and more practical. The simplified structure of a large charging system is presented in Figure 7.

The large charging system would likely need a 2-level load management in order to limit the ratings of the main distribution board at reasonable level. When using a two-level load management system, the total load of the main distribution board should be measured and the distribution loads should be controlled. Controlling can be implemented by a upstream programmable logic controller (PLC) or by software solution via a back-end system.

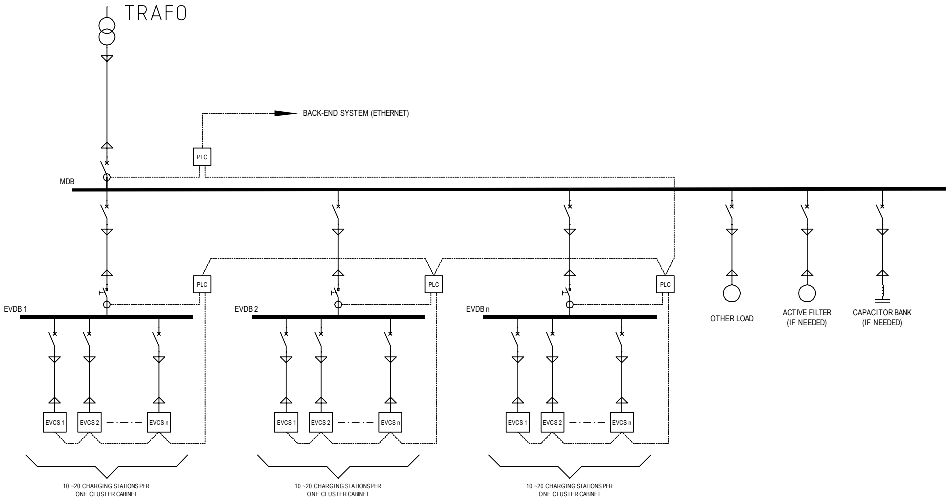


Figure 7: Large charging system

In the larger systems, the structure of EV charging system should be a satellite system. This allows system expansion cluster by cluster. That means that all charging stations are not supplied from the main distribution board directly. Therefore, a more cost-efficient way would be to supply the charging stations from the cluster cabinets. Hence, cable lengths, voltage drops and the needs of cable raceways decrease. This forms a significant share of the costs because the cabling and the cable raceways constitutes a 15-25 % of the total investment costs. Additionally, the components of the sub distribution boards are less expensive than the main distribution board as the short circuit current of the main distribution board is higher. The share of total investment costs of a distribution boards is about 20-30 %.

Figure 8 presents the distribution of costs of EV charging project. The costs are based on the commercial tenders of the existing projects.

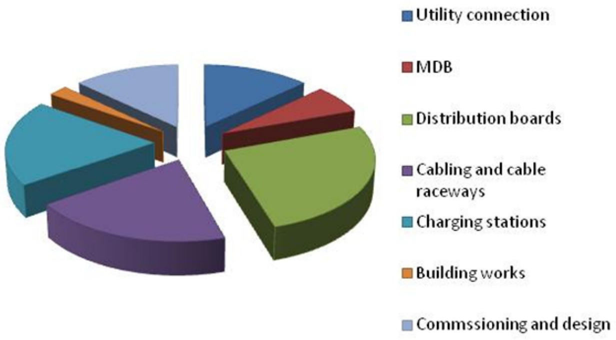


Figure 8: Distribution of costs

As much as the EV charging distribution is separated from the other load, the easier is the implementation of load management. The load monitoring and the load management is more practical when the EV distribution is separated from the other loads.

The larger installations may need own transformer due to the power demand. This should be taken into account in design phase. Because adding an additional transformer to the existing premises may be even impossible due to structural limitations. Typically, the technical spaces are very limited.

2.6 Management system

A management system or a back-end system integrates the different components, that enables communications between different parties. For example, the following parties may be integrated into the back-end system; EV charging system operation, maintenance, payments, user identification and communication. The back-end system is mainly a browser-based management tool. The back-end system can be installed into PLCs in the cluster cabinets, client own servers, cloud-base solutions or the dedicated server system whereas system provider dedicates servers to a client use. The cloud and the server solutions means that the all charging stations must be connected to the internet (hard wired or 3G e.g.). In PLCs solutions is enough that PLCs are cabled to the internet. Anyway this may cause some needs for the building structured cabling systems.

The back-end systems are generally manufacturer free if the charging station and the back-end system are compliant with the Open Charge Point Protocol (OCPP). The OCPP is an open standard. The OCPP defines basic components and functions for the communication between the EV charging stations and the back-end system. For example, the back-end system can control the charging station e.g., limiting the charging current. This increases the flexibility and the freedom of competition due to the back-end system is not dependent on the manufacturer of the charging station. For example, the back-end system provider can be changed without modifications for the existing charging infrastructure. (Open Charge Alliance, 2016)

A centralized maintenance, alarm and information messages are very important concerning managing the EV charging infrastructure. For example, in Financial times London report status of charging stations in London concerning charging stations " more than 40 per cent of the charging posts are out of service". That is consequence of lack of the maintenance. (LTD, 2015)

A charger identification can be implemented some different ways. The idea of identifications is that the used time and the used energy can be charged from right person. Consequently, the all charging events can be individualized by an event ID, a user ID, a used energy, a charging time and an event time (year, month, starting time, end time). The most common identification methods are a RFID-tag, a PIN-code, a mobile phone and voucher based solutions.

The back-end system enables the different charging priorities such as a standard user, a visitor, a VIP etc. The different priorities enables to use different charging profiles such as the VIP user get always the full charging power and the same time other users get less energy.

2.7 Effects on power quality

Inductive non-linear loads (e.g., three-phase AC controllers, thyristors, frequency converter) and inductive linear loads require a reactive power to produce a magnetic field. For economical and technical reasons the best place for compensate for the reactive power is as close as possible to the load. These reasons are

- to provide better voltage stability
- to provide higher energy efficiency due to reduction in power system losses
- to decrease investment costs by economic utilization of the equipment capacity

The electric devices and the components are designed operate by a sinusoidal waveform. Alternatively part of electrical influenced to sinusoidal waveform. A large EV charging system may effect significantly on the power quality. Hence, the following factors affect on the power quality

- Variations in the frequency
- Variations in the voltage
- Variations in the wave shape as commonly harmonics distortion
- Supply interruptions.

Because of the charging of EVs is executed by the charger, which are based on the three-phase bridge circuit it is very important take into account the power quality. (Hartmut Kiank and Wolfgang Fruth, 2011)

The harmonic distortion at an electrical system is a distorted and deviated of the voltage or the current waveform from the sinusoidal waveform. The harmonic currents causes by the nonlinear connected to the distribution system are flowing through the system impedances and in turn distorts the supply voltage. The power electronics are one of the causes of distortion. The power electronics is needed in the EV charger for convert the power from the AC to the DC form. The main risks of harmonics are

- Distortion of a voltage
- Overload of the distribution network
- Overload of the neutral conductor
- Additional loss of the energy
- Interferences. (Schneider Electric, 2015)

If the distortion of voltage is very large that can causes a very harmful effect on the sensitivity electric equipment(e.g. lighting, IT, frequency converters) and even the EVs themselves.

Because the EV charging is not a linear load (amount of EVs variable) is recommended to use an active power filters especially in the large installations. The active filters enable an improvement in power quality aimed at perfect sinusoidal current and voltage than the passive filters.

There are many studies concerning the harmonics of EV charging. Study ”Current Harmonics of EV Chargers and Effects of Diversity to Charging Load Current Distortions in Distribution Networks” concluded that the charging may occurrence of significant harmonic cancellation when the multiple different types of EVs are connected for charging. (Kütt et al., 2014b)

The linear inductive current lags behind the system voltage by an angle ϕ . The current lags due to linear loads requiring reactive power to set up a magnetic field. The reactive power causes unnecessary costs because the reactive power is not a useful energy.

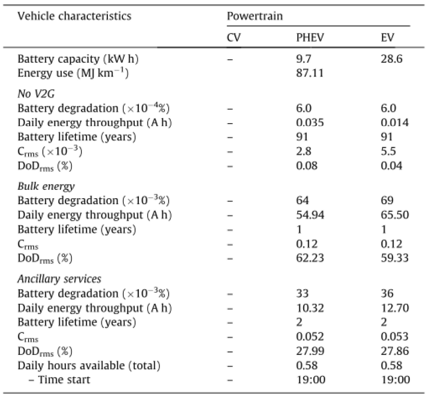
A compensation is usually implemented at the low voltage side by the capacitor banks. In the EV cases is recommended to use the automatic capacitor banks due to the irregular load. (Schneider Electric, 2015)

2.8 Vehicle to grid

One purpose of the smart grids is a load balancing. Especially, if some energy will be produced with the renewable source of energy (e.g. solar energy or wind energy) because almost the all renewable energy sources are very vulnerable to weather. Those depend heavily on the sun and wind to produce energy. In these cases the energy can be taken from the car batteries. The main principle of V2G (Vehicle-to-grid) is to use a large number of EVs batteries as power buffers of the grid. There are a lot of points in favor of V2G. When the network load is high and/or there are problems with the other energy sources, the EVs can generate the power to the grid. The main purposes of V2G are minimize costs and maximize the customers satisfaction. (Shima and Ona, 2015), (Youjie et al., 2015)

However, the biggest cons of V2G is that the lifetime of batteries reduces significantly when V2G is used (Table 4). Bishop et al. (2013) has reported that the lifetime of batteries reduced as much as from 91 years to 1 year due to the batteries durability can not withstand many time to charging and discharging.

Table 4: Comparison of battery lifetime (Bishop et al., 2013)



Vehicle characteristics	Powertrain		
	CV	PHEV	EV
Battery capacity (kW h)	–	9.7	28.6
Energy use (MJ km^{-1})		87.11	
No V2G			
Battery degradation ($\times 10^{-4}$%)	–	6.0	6.0
Daily energy throughput (A h)	–	0.035	0.014
Battery lifetime (years)	–	91	91
C_{rms} ($\times 10^{-3}$)	–	2.8	5.5
DoD_{rms} (%)	–	0.08	0.04
Bulk energy			
Battery degradation ($\times 10^{-3}$%)	–	64	69
Daily energy throughput (A h)	–	54.94	65.50
Battery lifetime (years)	–	1	1
C_{rms}	–	0.12	0.12
DoD_{rms} (%)	–	62.23	59.33
Ancillary services			
Battery degradation ($\times 10^{-3}$%)	–	33	36
Daily energy throughput (A h)	–	10.32	12.70
Battery lifetime (years)	–	2	2
C_{rms}	–	0.052	0.053
DoD_{rms} (%)	–	27.99	27.86
Daily hours available (total)	–	0.58	0.58
– Time start	–	19:00	19:00

2.9 Load management

A load management system balancing the charging current of EVs. The load management system limit the charging current so that the capacity of the supply network not exceeded. This enables to design and build more cost-efficiency systems than the systems without a load management.

Standard IEC 60364-7-722 defines that the each charging point is used as its rated current. This means in practice that the demand factor shall be 1. For example, if used 100 pcs mode 3 charging stations whit rated current 32 A. The size of installation must be 3200 A at least and plus other loads. This is illustrated as follows.

$$\Rightarrow 100pcs * 32A * 1 = 3200A$$

This causes over sizing and unnecessary costs. The demand factor may be reduced if the load control system is used. Generally the load management system decreases the load peaks and therefore enables the cost-effective EV charging system. The load management system supervise the total consumption and adapt the operation of charging station to optimize power consumption and energy costs without adversely affecting work efficiency and occupants comfort.

Standard IEC 61851-1 defines that the minimum charging currents to the vehicle when PWM is used (Table 5). The minimum duty cycle of 32 A charging is 8 % that means in current 6 A. Bellow 8 % duty cycles are not allowed. In the three-phase systems, the duty cycle value indicates the current limit per each phase. (IEC 61851, 2010)

In the larger installations this means that the one level load management is not relevant due to an unnecessary big utility connection. If used the 1 level load management the utility connection may increase unnecessary high. For example, 10 pc cluster cabinets á 250 A (16 pc 22 kW charging stations) means 2 500 A utility connection as minimum. However, if the second level load management is used can be the utility connection to decrease to 1 600 A.

Table 5: Maximum current to be drawn by vehicle. (IEC 61851, 2010)

Nominal duty cycle interpretation by vehicle	**Maximum current to be drawn by vehicle**
Duty cycle < 3 %	Charging not allowed
3 % ≤ duty cycle ≤ 7 %	Indicates that digital communication will be used to control an off-board DC charger or communicate available line current for an on-board charger. Digital communication may also be used with other duty cycles. Charging is not allowed without digital communication. 5 % duty cycle shall be used if the pilot function wire is used for digital communication
7 % < duty cycle < 8 %	Charging not allowed
8 % ≤ duty cycle < 10 %	6 A
10 % ≤ duty cycle ≤ 85 %	Available current = (% duty cycle) × 0,6 A
85 % < duty cycle ≤ 96 %	Available current = (% duty cycle - 64) × 2,5 A
96 % < duty cycle ≤ 97 %	80 A
Duty cycle > 97 %	charging not allowed
If the PWM signal is between 8 % and 97 %, the maximum current may not exceed the values indicated by the PWM even if the digital signal indicates a higher current.	

The load management system enables that the one charging station can assign the maximum output power (mode 3 type 2 22 kW). In practice, in the large installations all charging stations are never fully loaded at the same time. Further, the same time as splitting the load peaks at the load management will reach the cost-efficiency sizing of whole system. Figure 9 shows the function of the load management. The maximum power of the single charging station is 22 kW but in the cluster cabinet level is 10.8 kW per each charging station.

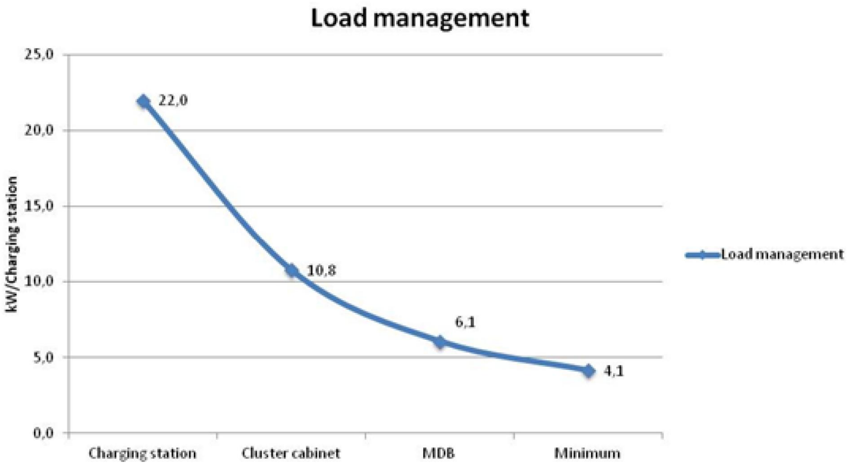


Figure 9: Load management

The idea of the load management is to provide the maximum capacity of the electricity to the EV charging and minimizing the charging time and also at the same time avoid overloading the system.

The pulse-width modulation (PWM) is a modulation technique to control the amount of power delivered to the EV without incurring the losses. The DC/AC inverter is needed due to that the DC energy source (battery) is fed with a AC source. The general DC/AC inverter is constituted by power electronic switches and power diodes. By increasing and decreasing the pulse width the charger regulates the energy flow to the batteries (Figure 10). By controlling PWM controller can be directly affected by the charging current of charger. The efficiency of PWM is very good due to that the conductive components are conductive or prevent current flow totally.

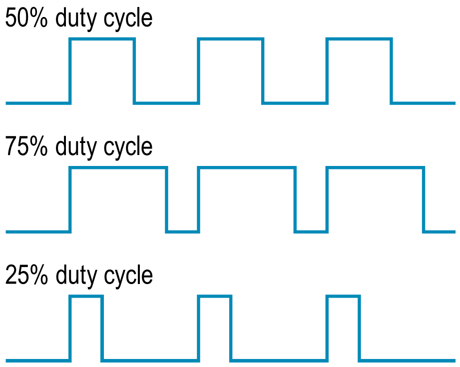


Figure 10: Duty cycle

The amount of duty cycles per one sinusoidal waveform depend on the product. However, the amount of duty cycles is several as per one waveform as seen in Figure 11.

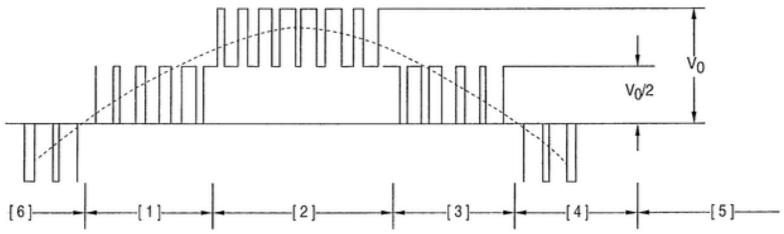


Figure 11: Duty cycle per one sinusoidal half wave (US 5517401 A, 1996)

A static load management means that the maximum charging current is limited to a specific value. This decrease the efficient of the charging system. For example, 10 charging stations (á 32 A) and the total current is limited to 200 A. If used only static load management it is necessary to set the maximum current to 20 A as per charging station (if the power is divided evenly). This causes that every charger get only 20 A even in that case that there is only one charger to charge.

A dynamic load management limit the total current so that the total current not exceeded. Further, the system divided the free capacity according to the calculation algorithm of the system.

The local load management control system based on the closed control system. Input variable is limitation of the maximum current e.g. rated current of distribution board. Control unit is PLC and feedback data is current measurement from charging stations.

In the semi-large installation where the first level dynamic load management is used by PLCs, server or cloud based systems. Every charging stations are connected to online. Load management system get real-time data from charging events. The algorithm calculates and adjustments the power balance. The maximum power can based on the fixed set point or the measurement data of main meter. For example, the load management system adjustment charging power that total power not exceed the rated capacity of sub distribution boards.

In the larger installations the load management system is reasonable to implemented in 2-level system. The first level operate in same way as mentioned above. However, the second level measures the main level and adjusts the maximum current of cluster cabinets. In this case there are two limiting value of charging station, the capacity of cluster cabinet and the capacity of main distribution board.

As discussed above, the management system enable the different charging priorities. These three modes are commonly used.

"First come, first serve" mode, the vehicle gets the information of the available energy amount till the scheduled departure of the car via a standard message. With this information, the vehicle start charging and reports it to the system. The required amount of energy will be reserved and is not available for other vehicles (Figure 12).

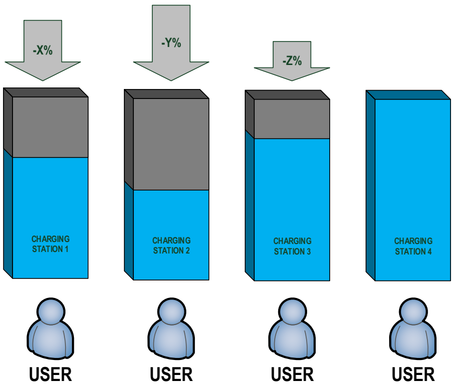


Figure 12: First come, first serve

”Proportional” mode, the output of each charging station is reduced by an identical percentage (Figure 13).

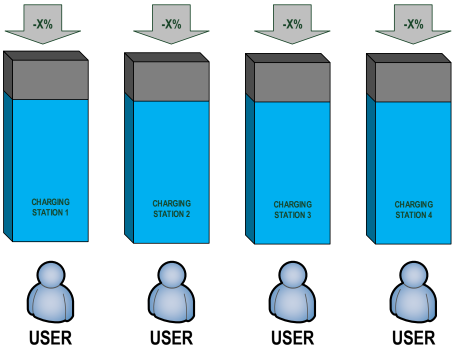


Figure 13: Proportional

”Privilege" mode, users with higher priority gets more energy than other users. For example, VIP user get a full amount of energy and the same time others charger will share the rest of capacity (Figure 14).

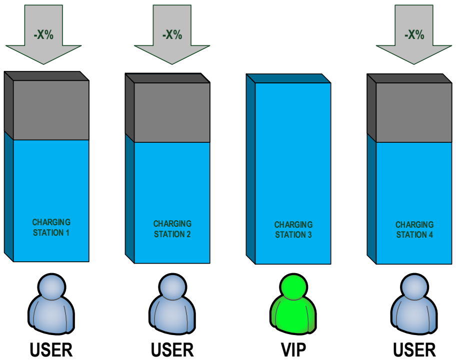


Figure 14: VIP

3 Design of electric vehicle charging system

Based on the literature review, the following sections explain the design procedure of the EV charging system as well as three case studies of building types parking building, hotel and shopping center.

3.1 Structure of distribution system

Starting an electrical design project the main issue is take into account the customer's needs. How many charging stations is needed, what kind of control and monitoring systems are needed but also what are the resources e.g. available utility connection and the budget of project. The design project is usually divided to different parts especially in larger project. For example, if project is divided in two part, the first part could be ”Feasibility study” or ”Basic design”. Therefore, in this design phase should be settle following tasks

- Client goal settings
- General system description
- Load analysis
- Cost plan

In the feasibility study phase should be defined at least following settings and initial data

- Amount of charging stations
- EV charging methods
- Main principles for management and back-end systems
- Time schedule

After the feasibility study phase will be done the necessary decisions to start detail design. In the detail design phase shall be done all necessary designs that project can be tendering and built such as the size of charging system, the requirements of back-end system and the control and monitoring systems.

The small installations, from 3 to 7 charging stations, can be installed to the individual distribution board and can be provide without the load management.

For example, if there are seven charging stations, 22 kW per each stations without the load management. According to standard the utilization factor shall be 1,0 if the load management not used. Therefore,

$$\Rightarrow 7 * 32A * 1,0 = 224A.$$

The result apparent that even less 10 charging stations increase the need of electricity capacity strongly if the load management system is not used.

The semi-large size installations, from 40 to 60 charging stations, the charging power is necessary to limit. For example,

$$\Rightarrow 50 * 32A = 1600A$$

Further, if the load management used, the needed capacity may decrease significantly,

$$\Rightarrow 50 * 32A * 0.2...0.4 = 320A...640A$$

3.2 Distribution boards and control boards

A distribution board of the EV system is no different from the usual building distribution board. However, there are some specific issues, which shall be take into account. The main distribution board (MDB) may including following equipment

- Surge arrester
- Earthing switch
- Main switch and commercial metering
- PLC and total energy metering
- Capacitor bank
- Harmonic filter
- Auxiliary supplies e.g. lighting
- Cluster cabinet supplies

Figure 15 shows the cluster cabinet supplies in the MDB. If the control and the measurement components are in the cluster cabinet, the supply is very basic.

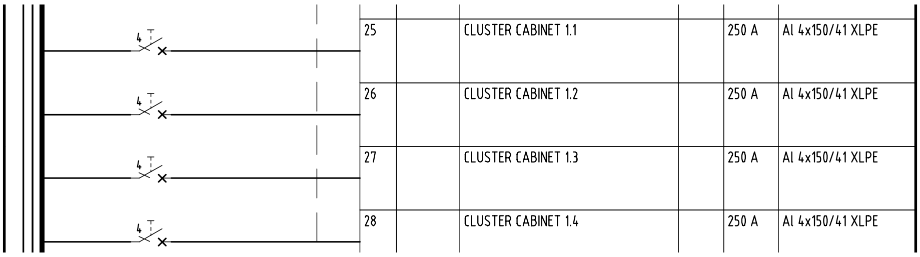


Figure 15: Extract from the MDB single line diagram

Figure 16 shows a layout example for the MDB, which supply 13 cluster cabinets. The size of MDB become easily very large. Additionally, if control and measurement components are in the cluster cabinets this allows system expansion cluster by cluster.

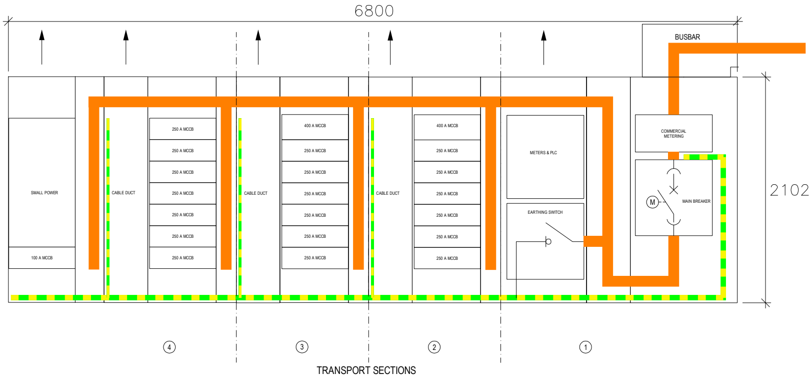
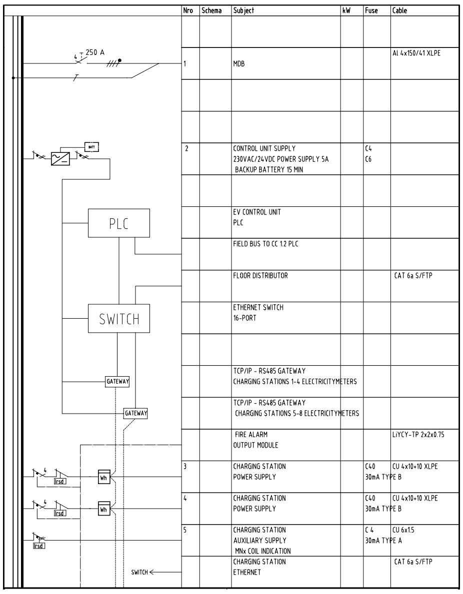


Figure 16: MDB layout

Therefore, cluster cabinets may including following equipment

- Main switch
- Metering
- PLC and communication devices
- Charging station supplies

Figure 17 shows extract single-line diagram: cluster cabinet main switch, PLC and communication device and some charging station supplies.



Nro	Schema	Subject	kW	Fuse	Cable
1		MDB			Al 4x150/41 XLPE
2		CONTROL UNIT SUPPLY 230VAC/24VDC POWER SUPPLY 5A BACKUP BATTERY 15 MIN		C4 C6	
		EV CONTROL UNIT PLC			
		FIELD BUS TO CC 1.2 PLC			
		FLOOR DISTRIBUTOR			CAT 6a S/FTP
		ETHERNET SWITCH 16-PORT			
		TCP/IP - RS485 GATEWAY CHARGING STATIONS 1-4 ELECTRICITYMETERS			
		TCP/IP - RS485 GATEWAY CHARGING STATIONS 5-8 ELECTRICITYMETERS			
		FIRE ALARM OUTPUT MODULE			LiYCY-TP 2x2x0.75
3		CHARGING STATION POWER SUPPLY		C40 30mA TYPE B	CU 4x10+10 XLPE
4		CHARGING STATION POWER SUPPLY		C40 30mA TYPE B	CU 4x10+10 XLPE
5		CHARGING STATION AUXILIARY SUPPLY MNx COIL INDICATION		C 4 30mA TYPE A	CU 6x1.5
		CHARGING STATION ETHERNET			CAT 6a S/FTP

Figure 17: Extract from the cluster cabinet single line diagram

Depending the manufacturer of charging stations, the energy meters and RCDs may be in the cluster cabinet or in the charging station.

The design of the main distribution board and the cluster cabinets should be conductive of temperature take into account due to that the breakers may be fully loaded. In this cases the breakers should be installed that there enough free space. Also the most loaded breakers should be installed on the top because heat rises from bottom to up.

3.3 Cabling and cable raceways

The capacities of cables and cable raceways shall be comply with standard IEC 60364. Based on the cabling costs and voltage drops, it is practical install the cluster cabinet near the charging stations. In this case the needed power will be supplied by the power cables near the load and additionally the total amount of cabling and cable raceways is less. The size of terminals shall be also take into account when the cables are selected. The fill ratio of cable raceways should not more than 60 percent because all cables may be fully loaded at the same time when temperature of cables may rise and also due to the t- and x-parts.

3.4 User profiles

A user profile in this context refers a typical using of EV charging. The user profiles can be used to assess the need of the power. The user profiles are always estimates but it give an indication the level of needs. The user profiles are a very important part of the design of EV charging system. Therefore, the important values are

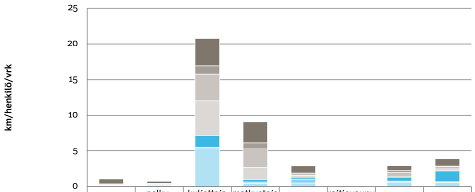
- Average charging duration
- Average charging time
- Average needed energy

The purpose and the location of charging station are the important factors regarding the user profile.

The user profiles, which are used in the simulations based on the Finnish, Swedish and English national travel surveys. (Finnish Transport Agency, 2012), (Sveriger officiella statistik, 2014), (Department for Transport UK, 2014)

For example, in the working places the most of workers come to the office in the morning and left in the afternoon. In generally the average charging will start at 8 to 9 in the morning and will be end from 3 to 5 in the evening. Consequently, the average charging time is roughly from 6 to 7 hours.

Table 6: Average travel distances



			henkilöauto					
	jalankulku	polkupyörä	kuljettaja	matkustaja	linja-auto	raitiovaunu metro	juna	muu
■ muu vapaa-aika	0,70	0,29	3,87	2,95	1,02	0,05	0,72	1,04
■ mökki	0,00	0,00	1,14	0,83	0,00	0,00	0,26	0,04
■ vierailu	0,06	0,07	3,76	2,67	0,34	0,02	0,60	0,35
■ ostos, asiointi	0,14	0,12	4,83	1,66	0,25	0,06	0,06	0,29
■ työasia	0,01	0,00	1,66	0,37	0,27	0,01	0,54	1,52
■ koulu, opiskelu	0,08	0,08	0,28	0,17	0,54	0,01	0,14	0,13
■ työ	0,07	0,17	5,26	0,45	0,49	0,09	0,61	0,53
kaikki	1,06	0,73	20,79	9,10	2,90	0,24	2,92	3,89

According to national travel survey of England a fifth of shopping trips are made on a Saturday and most shopping trips begin between 9 and 15. The average shopping trip is under 10 km. However, in the simulations used bigger distance due to that the EVs not necessary fully charged before shopping trip. Therefore, the average daily trip distance is used in simulations. Figure 18 shows the user profile of the office parking building. (Department for Transport UK, 2014)

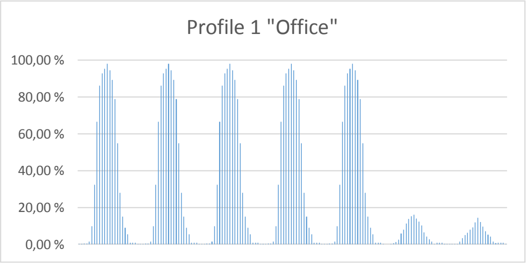


Figure 18: Profile 1

Shopping centers are usually closed in the night (parking facilities are also closed). The average shopping time is roughly on to three hours. Further, the maximum power need is quite large due to the peak of customers and the limit of charging time. On workdays the peak of customers in shopping centers is from 4 to 20 in evening. Figure 19 shows the user profile of the shopping center. (Department for Transport UK, 2014)

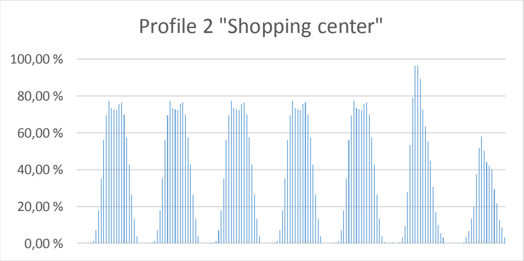


Figure 19: Profile 2

Some hotel customers leave their cars at hotel during whole staying at hotel. However, in generally all customers at the hotel stay in the hotel night time. Figure 20 shows the user profile of the hotel. (Department for Transport UK, 2014)

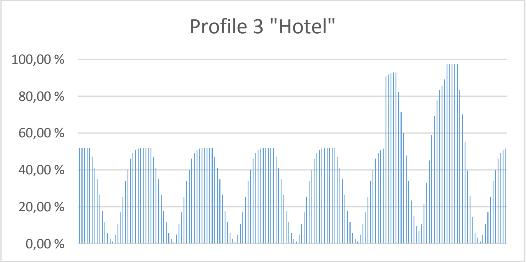


Figure 20: Profile 3

3.5 Case studies

In this section studied how different places impacts on the designs and structure of the EV charging system. The case studies are selected based on the literature review. Regarding the literature review, the parking areas in the work places, hotels and shopping centers are the potential places for the large scale charging systems.

The case simulations were made by using a simulating spreadsheet software (Excel). Software using for the simulation following input data

- Amount of charging stations (1 x 22 kW)
- Amount of fast charging stations (1 x50 kW)
- Profile (1, 2 or 3)
- Other loads (e.g. lighting load) (kW)
- Cos ϕ
- Voltage level

- Reserve (%)

Software calculates the maximum needed power. Depending on the selected profile the software calculates the needed power using the demand factor. Following data are used to calculate the demand factor

- Capacity of batteries
- Range of EV
- Charging power
- Average trip distances per day (depends on selected profile)
- Average charging time (depends on selected profile)

A required charging energy is obtained using a capacity of batteries, a range of EV and an average trip distance. A demand factor is obtained of using a charging energy, a charging power and a charging time.

Used the capacity of batteries and the range of EV are higher than the average values nowadays (Table 1). Because the life time of electrical installations are up to 30 years. Additionally, is it expected that the trends is increasing concerning the capacities and the ranges of EVs.

The simulation results are destined for estimating needs, not for exact rating. Additionally, with the simulation software can be done a sensitivity analysis. Which can be studied different solutions by changing the input data.

3.5.1 Parking building

A parking building in this context refers parking facilities of a work place for example, office buildings. The average working time of normal office worker is between 6 to 9 hours. Moreover, the most of workers stay at office whole day. Alternatively, some of the workers need their cars during the day (e.g., sales men). This ratio should be studied because of it causes to the average charging time.

Usually loads are very small in the parking buildings in practice, lighting load mainly. Conversely, the EV charging load may are much bigger than the other load.

The main criterias in this simulation were that EVs charged from 20 % to 100% during the day but in addition users which need EVs during the day (e.g., site meetings) is recommended reserve some free capacity for example, fast charging stations or priorities system.

Table 7 presents the assumptions for parking building. Basically assumed that the main users of parking building are the office workers, which are most of the day at office. In that case, the average charging time is quite long up to 6 hours. The other load is 100 A mainly lighting load.

Table 7: Assumptions of parking building case study.

Description	**Value**
Amount of charging stations	400
Amount of fast charging stations	2
Profile	1
Other load	100 A
Demand factor for other load	1
Cos ϕ	0,95
Voltage %	400 V
Capacity of batteries	90 kWh
Range of EV	200 km
Maximum charging power	22 kW
Average trip distance	60 km
Average charging time	6 h
Reserve	15 %

3.5.2 Shopping center

The competition of shopping centers has increased by reason of new competitors but also growth of online retail sales (Helsingin Sanomat, 2016). Many shopping centers and especially new shopping centers are designed that they are accessible by cars and hence also EVs. Thus, one option to lure customers could be an effective EV charging system. However, the investment and operating cost should not be too much in relation to the benefits.

Table 8 presents the assumptions for shopping center. The assumptions based on large or semi-large ”car shopping center” corresponding to the size of Jumbo, Kaari, Itäkeskus or Sello by for example. There are 50 EV charging stations for regular customers but also 10 fast charging stations. The other loads are consist of mainly a lighting and a ventilation loads. Therefore, the other loads are estimated to 100 A.

Table 8: Assumptions of shopping center case study.

Description	**Value**
Amount of charging stations	50
Amount of fast charging stations	10
Profile	2
Other load	100 A
Demand factor for other load	1
Cos ϕ	0,95
Voltage %	400 V
Capacity of batteries	90 kWh
Range of EV	200 km
Maximum charging power	22 kW
Average trip distance	60 km
Average charging time	2 h
Reserve	15 %

3.5.3 Hotel

As like as shopping centers the competition of hotels is also fierce. A one important issue that customers consider is the parking space if they arrive with a car. Parking spaces of hotels are such as normal parking building commonly. However, the user profile of hotels is different than user profile of office parking spaces. Table 9 presents the assumptions for hotel.

Table 9: Assumptions of hotel case study.

Description	**Value**
Amount of charging stations	50
Amount of fast charging stations	2
Profile	3
Other load	50 A
Demand factor for other load	1
Cos ϕ	0,95
Voltage %	400 V
Capacity of batteries	90 kWh
Range of EV	200 km
Maximum charging power	22 kW
Average trip distance	150 km
Average charging time	12 h
Reserve	15 %

4 Results

This part of the thesis discusses the findings which emerged from the case studies presented in the previous chapter.

4.1 Design practices

The main goal of the current study was to determine the impacts of EVs charging on building electricity distribution systems. There were four primary aims of this study: 1. To provide the typical design documents of EV charging system 2. To settle the impacts on the power calculations 3. To settle the typical structures of the EV charging systems.

The result of this study were the following typical design documents of EV charging

- Explanatory note
- Layout examples
- Single-line diagrams
- EV system diagrams
- Main distribution board diagrams
- Sub distribution board (cluster cabinet) diagrams
- List of equipment

These documents can not be presented on this study because the documents are trade secrets.

The field of EVs develops very fast so the technical standardisation of EVs is not fully unambiguous. Standards not take any position regarding the structure of EV charging system, the power calculations if the load management it used or the program interfaces. However, the safety standards are clear and up to date. There are also lot of variations between different manufacturers and therefore there are not established practices.

Therefore, the Excel simulation model was made. The case studies were simulated by the simulation model (see appendices). The major uncertainty of power calculations is that there are very limited number of the practical information of large EV charging systems. Further standardization of peak load evaluations is recommended.

The typical structures of the EV charging system are presented in section 2.5. The basic idea of structures is that the EV charger and other load should be separate as much as possible. Therefore, the management and control of EV charging system would be much practical.

The large EV charging systems may cause some impacts on the power quality. Therefore, the space reservation for the capacitor bank and the harmonic filter is recommended.

4.2 Case studies

4.2.1 Parking building case study

The result of simulation of parking building case study is that the demand factor is 0,2 and the needed total apparent power is roughly 2300 kVA (Table 10).

Table 10: Result of parking building simulation.

Description	**Value**
Demand Factor	0,20
Total apparent power	2292 kVA
Total current	3308 A
kW/Connecting point	4,5 kW

In this case the transformer rating should be 2500 kVA or the amount of EVs should be decreased little bit so that 2000 kVa transformer can be installed. Comparing the basic parking building the peak load is much higher than the regular parking building. It may concluded that when building new parking building and not yet want to invest in EV charger it recommended to reserves spaces for transformer and distribution boards.

The correlation between maximum power without load management and with load management is interesting because that shows how much there may be a variation.

4.2.2 Shopping center case study

The result of simulation of shopping center case study is that the demand factor is 0,26 and the needed total apparent power is 418 kVA (Table 11).

Table 11: Result of parking shopping center.

Description	**Value**
Demand Factor	0,61
Total apparent power	1308 kVA
Total current	1888 A
kW/Connecting point	13,5 kW

In this rating of the distribution board should be 800 A. It may concluded that this installation need not necessary individual transformer. However, if the EV charging system is connected to the same network than the other distribution of building the power quality should be specially take into account.

4.2.3 Hotel case study

The result of simulation of hotel case study is that the demand factor is 0,26 and the needed total apparent power is 418 kVA (Table 12).

Table 12: Result of hotel simulation.

Description	**Value**
Demand Factor	0,26
Total apparent power	418 kVA
Total current	603 A
kW/Connecting point	5,6 kW

In this rating of the transformer should be 1600 kVA. It may concluded that when building new hotel or renovate parking facilities and not yet want to invest in EV charger it recommended to reserve spaces for transformer and distribution boards. Also the power quality should be take into account especially due to there may be sensitive equipment near.

5 Conclusions and summary

In this study, the aim was to assess the main impacts of the EV charging system on building distribution system. The research data in this thesis was drawn from a literature review of related work as well as three case studies of building types parking building, hotel and shopping center.

One interesting finding was that how much variations are to design the EV charging system. Thus, the design process consist of selection of the components, the structure of charging system and the back-end system. Similar functions can be provided many different ways. Moreover, the field of EVs developing rapidly and therefore the established practices has not yet formed.

This study has identified the parts of the design of EV charging system. This study has shown that how important is design process. Furthermore, this emphasized larger systems. The most important issues are the structure of charging system and power calculations. However, not forgetting the cost-effectiveness and life-cycle costs. The EV design process is the sum of many different pieces. To reach a good outcome of the project all parts shall be take into account.

Based on the case studies EV charging system may increase significantly the need of electricity capacity. Hence, the simulation of use is very important phase of the design process. What is surprising is that the difference between user profiles are significant. The average charging times and the period to charge influences strongly to the demand factor. The simulations are estimates but it give an indication the level of needs. Furthermore, the limitations of measured data of large EV charging systems that there are some uncertainty of the simulations.

In conclusion, electrical measurement data combined with data of other sources like occupancy information and car types should be analyzed to verify load profiles to create parametrized functions with aim to evaluate load needs at early stage of design. Further standardization of peak load evaluations is recommended.

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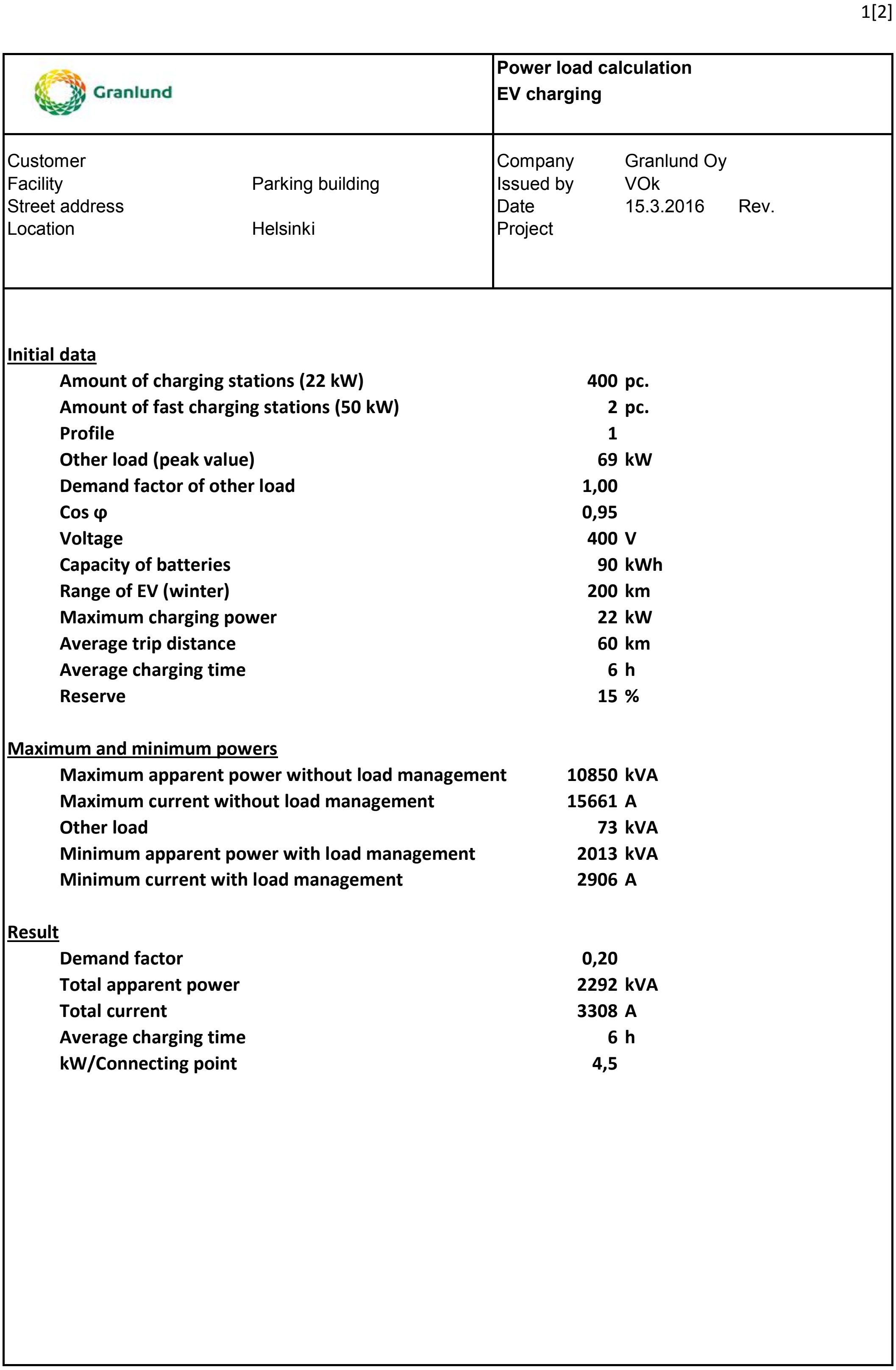
A Parking building power load calculation



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Granlund

Power load calculation
EV charging

Customer		Company	Granlund Oy		
Facility	Parking building	Issued by	VOk		
Street address		Date	15.3.2016	Rev.	
Location	Helsinki	Project			

Initial data

Amount of charging stations (22 kW)	400	pc.
Amount of fast charging stations (50 kW)	2	pc.
Profile	1	
Other load (peak value)	69	kW
Demand factor of other load	1,00	
Cos φ	0,95	
Voltage	400	V
Capacity of batteries	90	kWh
Range of EV (winter)	200	km
Maximum charging power	22	kW
Average trip distance	60	km
Average charging time	6	h
Reserve	15	%

Maximum and minimum powers

Maximum apparent power without load management	10850	kVA
Maximum current without load management	15661	A
Other load	73	kVA
Minimum apparent power with load management	2013	kVA
Minimum current with load management	2906	A

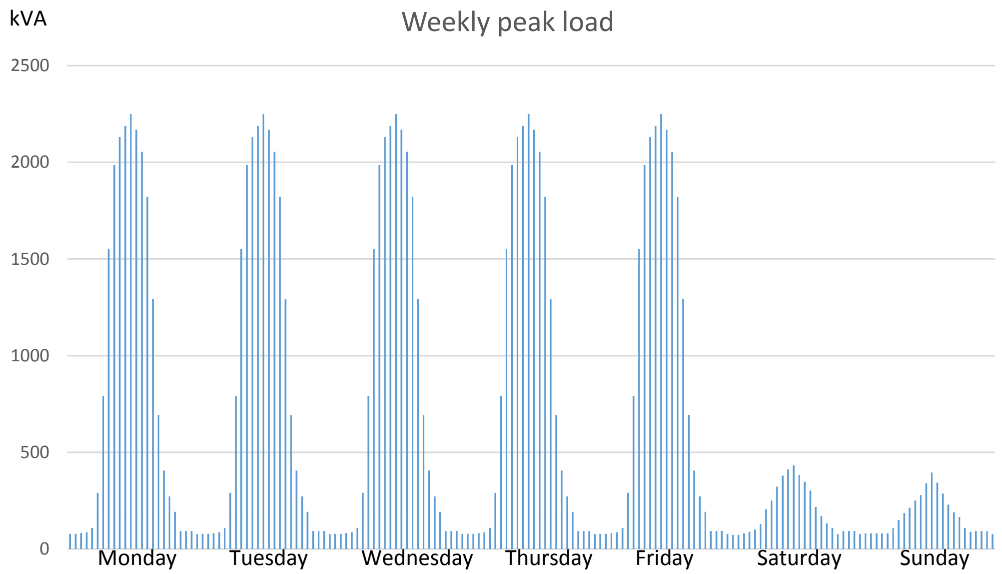
Result

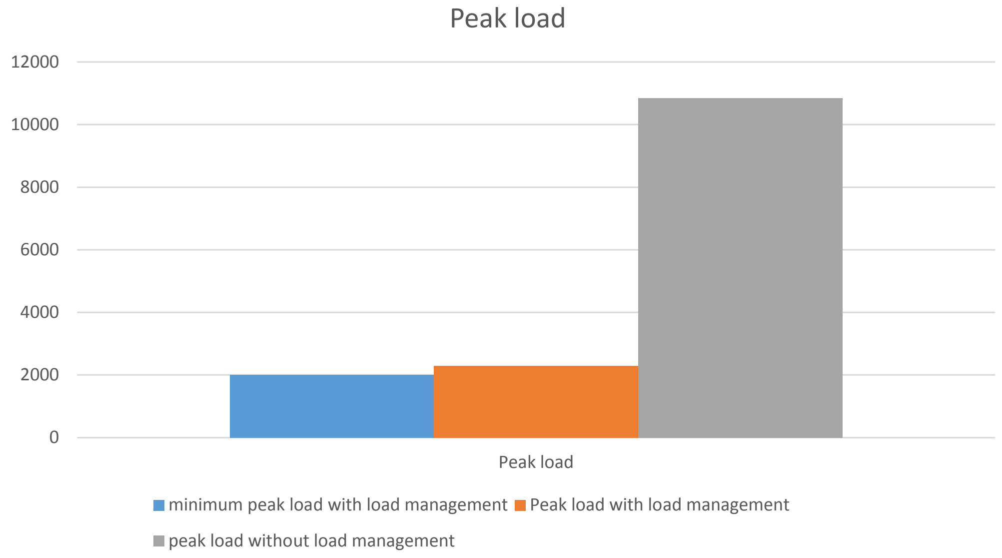
Demand factor	0,20	
Total apparent power	2292	kVA
Total current	3308	A
Average charging time	6	h
kW/Connecting point	4,5	

Granlund

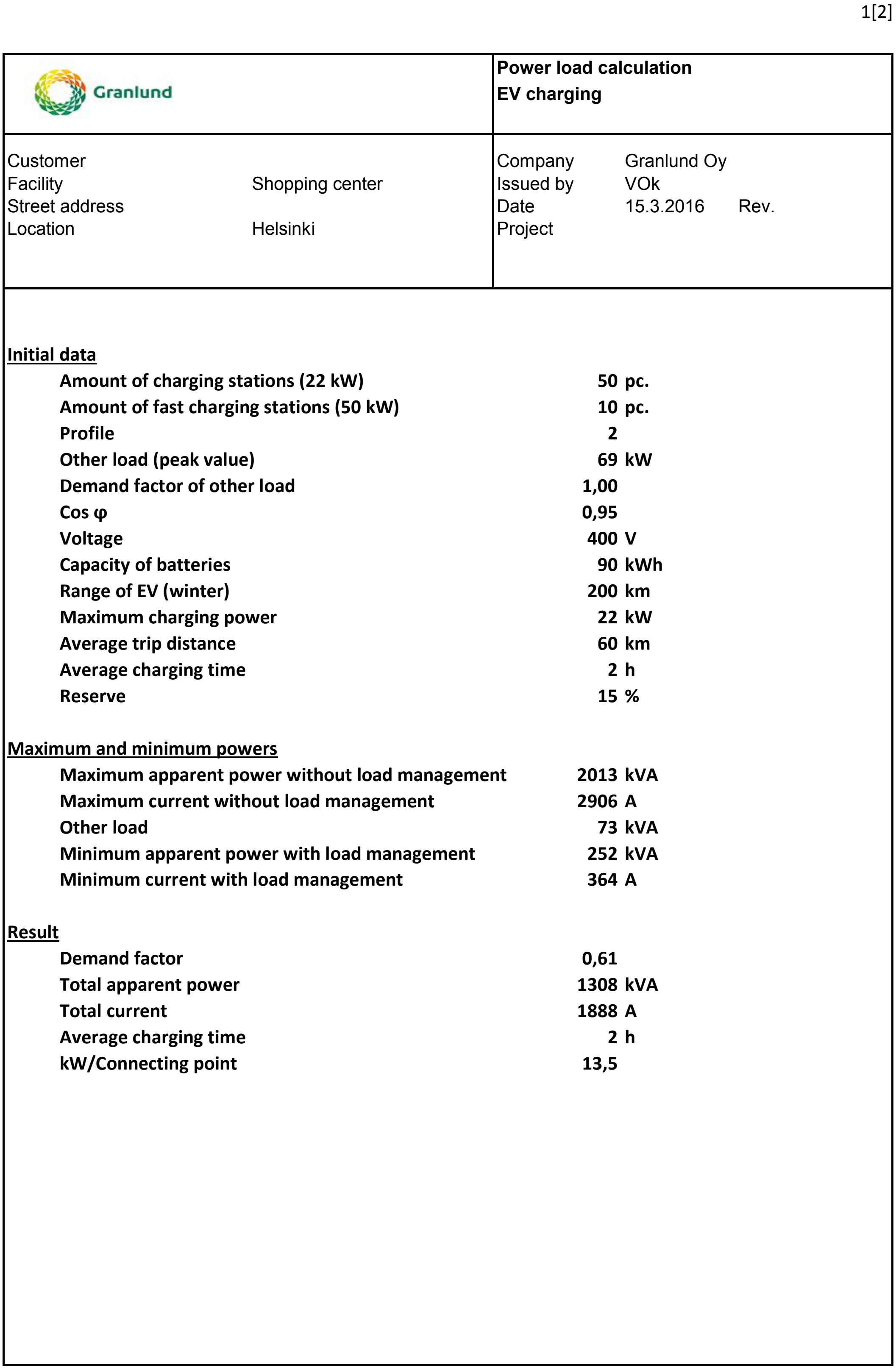
Power load calculation
EV charging

Customer		Company	Granlund Oy	
Facility	Parking building	Issued by	VOk	
Street address		Date	15.3.2016	Rev.
Location	Helsinki	Project		





B Shopping center power load calculation



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Granlund

Power load calculation
EV charging

Customer		Company	Granlund Oy
Facility	Shopping center	Issued by	VOk
Street address		Date	15.3.2016 Rev.
Location	Helsinki	Project	

Initial data

Amount of charging stations (22 kW)	**50**	**pc.**
Amount of fast charging stations (50 kW)	**10**	**pc.**
Profile	**2**	
Other load (peak value)	**69**	**kW**
Demand factor of other load	**1,00**	
Cos φ	**0,95**	
Voltage	**400**	**V**
Capacity of batteries	**90**	**kWh**
Range of EV (winter)	**200**	**km**
Maximum charging power	**22**	**kW**
Average trip distance	**60**	**km**
Average charging time	**2**	**h**
Reserve	**15**	**%**

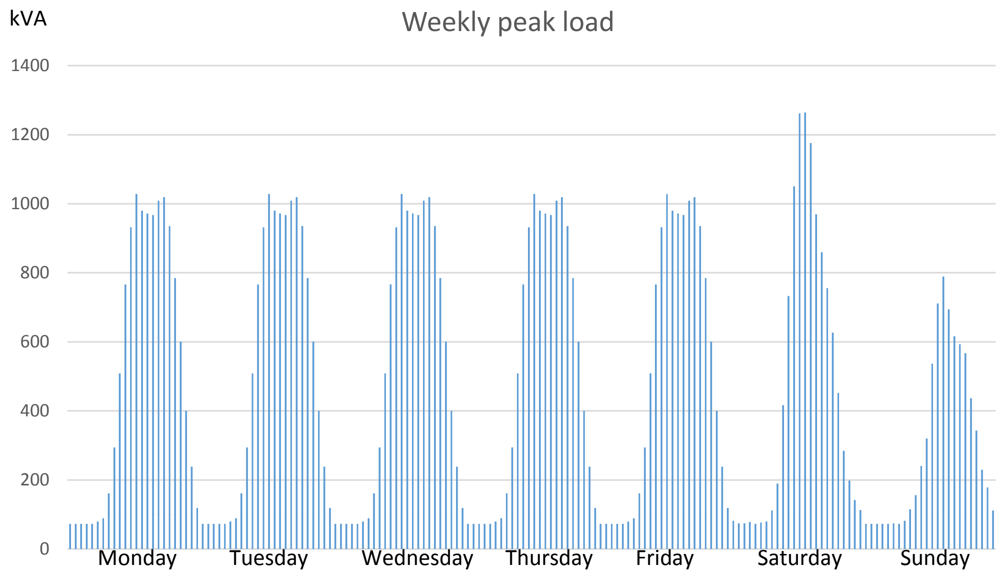
Maximum and minimum powers

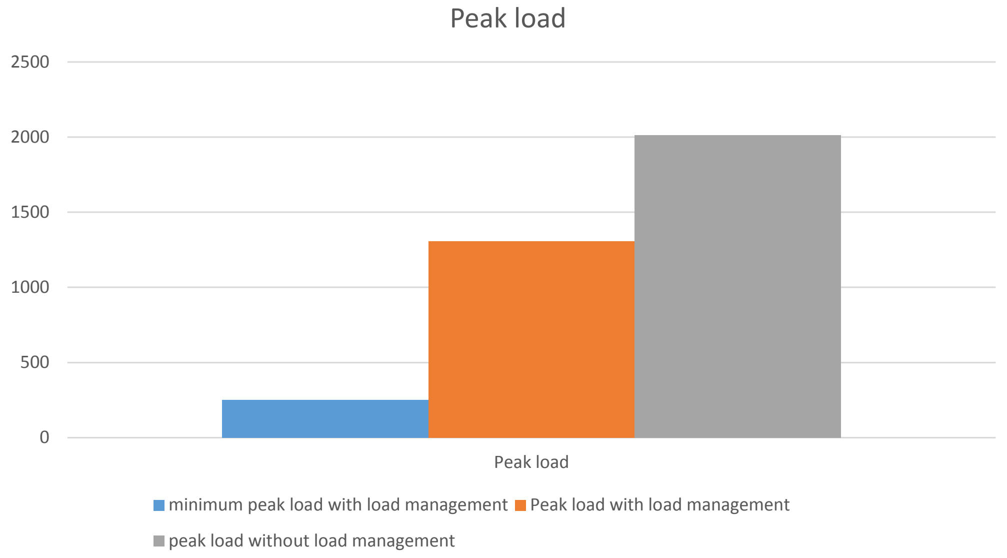
Maximum apparent power without load management	**2013**	**kVA**
Maximum current without load management	**2906**	**A**
Other load	**73**	**kVA**
Minimum apparent power with load management	**252**	**kVA**
Minimum current with load management	**364**	**A**

Result

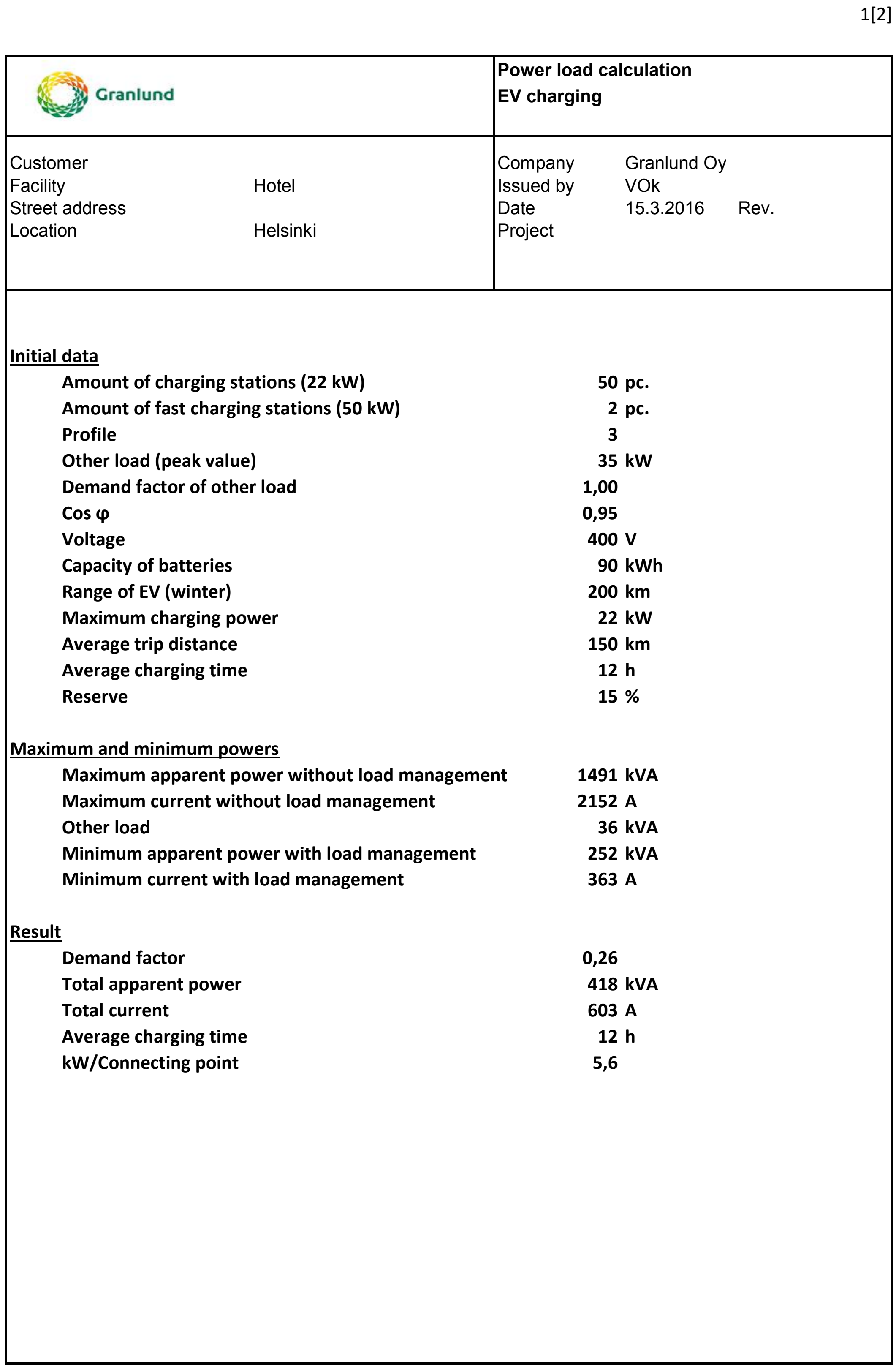
Demand factor	**0,61**	
Total apparent power	**1308**	**kVA**
Total current	**1888**	**A**
Average charging time	**2**	**h**
kW/Connecting point	**13,5**	

Granlund	**Power load calculation** **EV charging**
Customer Facility Shopping center Street address Location Helsinki	Company Granlund Oy Issued by VOk Date 15.3.2016 Rev. Project





C Hotel power load calculation



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Granlund

Power load calculation
EV charging

Customer		Company	Granlund Oy
Facility	Hotel	Issued by	VOk
Street address		Date	15.3.2016 Rev.
Location	Helsinki	Project	

Initial data

Amount of charging stations (22 kW)	**50**	**pc.**
Amount of fast charging stations (50 kW)	**2**	**pc.**
Profile	**3**	
Other load (peak value)	**35**	**kW**
Demand factor of other load	**1,00**	
Cos φ	**0,95**	
Voltage	**400**	**V**
Capacity of batteries	**90**	**kWh**
Range of EV (winter)	**200**	**km**
Maximum charging power	**22**	**kW**
Average trip distance	**150**	**km**
Average charging time	**12**	**h**
Reserve	**15**	**%**

Maximum and minimum powers

Maximum apparent power without load management	**1491**	**kVA**
Maximum current without load management	**2152**	**A**
Other load	**36**	**kVA**
Minimum apparent power with load management	**252**	**kVA**
Minimum current with load management	**363**	**A**

Result

Demand factor	**0,26**	
Total apparent power	**418**	**kVA**
Total current	**603**	**A**
Average charging time	**12**	**h**
kW/Connecting point	**5,6**	

Granlund		**Power load calculation** **EV charging**		
Customer		Company	Granlund Oy	
Facility	Hotel	Issued by	VOk	
Street address		Date	15.3.2016	Rev.
Location	Helsinki	Project