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Load Management Solutions for Electric Vehicle Chargers in a Software as a Service Platform

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Abstract

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Electric vehicle charging poses a problem to the current electrical system infrastructure. The total energy consumption can rise to an exceptionally high level when multiple EV charging stations are using high power simultaneously. Electrical system overload is risky because it can lead to power outages and high-cost electrical bills. The problem can be resolved by upgrading hardware on the charging site. However, it is not cost-efficient.

This thesis presents an alternative solution by utilizing load management. The main goal of this project was to design and implement load management solutions for electric vehicle chargers in the cloud platform. Solutions were developed utilizing microservice architecture, and various technologies were used: Docker, Kubernetes, React.js, Node.js, Express, Redis, PostgreSQL, and TimescaleDB. Power consumption on the site was measured with an external hardware module. Solutions support chargers that operate on Open Charge Point Protocol version 1.6 JSON.

Dynamic Load Management distributes available power evenly among all the active charging stations on the site. Adaptive Load Management reacts to the real-time change in energy consumption on the site and distributes available power accordingly to the charge points. Both solutions were continuously tested with genuine chargers and electric cars. Upon test results, needed changes were implemented.

This thesis also covers current implementation disadvantages and suggests possible improvements.

Keywords: electric vehicles, charging stations, charge points, electrical demand, power consumption, demand response, load management, dynamic load management, adaptive load management, energy services, charging infrastructure

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Appendix 2. Tests

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List of Abbreviations

DLM:	Dynamic Load Management.
ALM:	Adaptive Load Management.
EV:	Electric Vehicle.
kW:	Kilowatt.
A:	Ampere.
SaaS:	Software as a service platform.
PHEV:	Plug-in Hybrid Electric Vehicle.
BEV:	Battery Electric Vehicle.
DSM:	Demand-side management.
AC:	Alternating current.
DC:	Direct current.
V:	Volt.
EVSP:	Electric Vehicle Service Provider.
EVSE:	Electric Vehicle Supply Equipment.
OCPP:	Open Charge Point Protocol.
TCP/IP:	Transmission Control Protocol / Internet Protocol.
SOAP:	Simple Object Access Protocol.
JSON:	JavaScript Object Notation.
OCPP-J:	OCPP via JSON over WebSocket.
CSMS:	Charging Station Management System.

SECC: Supply Equipment Communication Controller.

CCS: Combined Charging System.

LLC: Low-level Communication.

HLC: High-level communication.

PWM: Pulse-width modulation.

PLC: Power Line Communication.

OSI: Open System Interconnection.

URL: Uniform Resource Locator.

1 Introduction

The demand for electric vehicles (EV) has been increasing drastically over the past few years. According to Global Opportunity Analysis and Industry Forecast 2020–2027 report, in 2019, the EV market was worth 162.34 billion US dollars and is forecasted to reach 802.81 billion US dollars by 2027. [1] Electric car deployment has been growing speedily, and it is wildly expected that electric vehicles will become a primary part of the road transportation system shortly.

Increasing demand for electric vehicles contributes to the more significant electricity consumption. The US Energy Information Administration states that world energy consumption will grow by almost 50% between 2018 and 2050. [2]

High electrical power is required in order to charge electric vehicles. Several issues regarding high-energy consumption will arise on a site with a considerable number of electric vehicles charging stations. The significant effect of EV charging with high penetration levels on the power system is shown in many studies. [3, 4] The total power peak of the cables supplying the charging station group can rise to an exceptionally high level when multiple EV charging stations using high power. An unexpected high rise in electricity consumption can lead to a power outage if the existing electrical infrastructure cannot handle a higher current. Avoiding this situation would require an infrastructure improvement, which is not cost-effective. [5] A residential or commercial building aiming to provide charging for 20 electric cars and having 22 kW charging plugs (3 phases x 32 A) would require a 3 x 640 A electricity connection which costs tens of thousands of euros. [6]

Load management is necessary to distribute the EV charging load and prevent the power system overload during peak hours. [7] Dynamic and Adaptive Load Management (DLM, ALM) solutions provide a more intelligent and more cost-efficient way to manage the energy consumption on the property effectively. For EV charging, DLM and ALM stand for optimizing charging loads to assure distribution of power among all charging EVs considering the available capacity. It provides a way to utilize the full potential of the available to EV charging site capacity with respect to the maximum power capacity.

This project focuses on designing and implementing Dynamic and Adaptive Load Management solutions for different EV charging stations in a Software as a Service (SaaS) platform. Fixed and variable capacities are supported, as well as different charger types and models.

1.1 Thesis Aim and Objectives

The project reviewed in this thesis aims to design and implement versatile load management solutions for electric vehicle chargers. The research work was carried out in the Finnish company “Liikennevirta Oy (Virta)” [8]. Virta provides diverse charging services to customers through the SaaS platform.

The research objectives include:

- To outline the logic for the Dynamic and Adaptive Load Management solutions.
- To design the user interface for the solutions.
- To investigate how charging stations and external hardware - cloud gateway and power meter - work.
- To investigate how the solution can support different EV charger brands and models.
- To investigate which OCPP commands are suited for the need of changing necessary parameters.
- To implement the designed solution in the Virta management platform.
- To test the solution according to the test scenarios and customer requirements.

1.2 Electric vehicles market outlook and forecast

The noticeable changes in the global electric vehicles market started a decade ago, and the rapid growth of the number of light EV’s (include Plug-in Hybrid Electric Vehicle (PHEV) and Battery Electric Vehicle (BEV)) around the world has been consistent.

The year-on-year growth in the number of electric cars has been above 30% since 2016. In 2018, the yearly growth rate was at the mark of 63%, and the number of electric vehicles worldwide was at a record point of passing 5.1 million units, which exceeded by 2 million the total number of EV’s in 2017. Almost a half (45%) of the electric vehicles were registered in China, amounting to 2.3 million cars. Europe’s share of total EV number was 24%, and the United States accounted for 22%. At the same time, the global number of charging points was near 5.2 million. [9]

In 2019, electric car sales grew by 6%, which is less significant than the previous year. The total number of EVs worldwide increased by 2.1 million, topping up the stock to 7.2 million units. One of the primary reasons for the market slowdown was the reduction of the purchase and tax subsidies in China and the United States, which significantly affected the global market resulting in the relatively small total growth percentage. However, this helped to shine a light on the electric car sales in Europe that increased by 50% in the same year. There were around 7.3 million chargers worldwide in 2019. [9]

In 2020 global electric vehicles market and the auto industry were seriously affected by the covid-19 pandemic. Based on sales data from the first quarter of 2020, the EV sales rate had declined by 25%. [10] It is hard to accurately predict how long the pandemic's impact will last and how much it will affect the future development of the market. Many variables remain unknown: possible following pandemic waves, the rate of economic recovery, factory production disruptions, and interruptions in the supply chain. [9]

However, by the end of 2020, about 3 million electric vehicles were sold, and there were 10 million electric vehicles on the roads. Despite the global sales of all cars dropping by 6%, the registration of EVs increased by 41% in 2020. Beginning 2021 showed significant growth in global EVs sales. It grew by 140% in comparison to the same time in 2020. [11]

Predictions that are more detailed will be observed for the three giants of the electric vehicles global market: China, Europe, and United States.

China had established vital targets to reduce CO2 emissions, lifted off the EV’s purchase tax, and extended the purchase subsidies until 2022. From January to April of 2021, around 500 thousand electric cars were sold in China. [11] The projection is that by 2022 the number of electric cars sold in China will increase up to 3.5 million in comparison to 1.2 million EV’s being sold in 2019. [12] China targets to electrify 70% of passenger cars by 2025 and reach 100% by 2035. [13]

Europe reached to meet the fleet-wide average CO2-emission target by 2021. Many electric vehicle manufacturers based in Europe and targeting the European market have committed to having EV emission levels at 95 g CO2/km and introduced 42 new electric car models during the first quarter of 2020. The governments of European countries established taxation benefits and purchase subsidies to promote EV usage and support more environmentally friendly mobility. The measures were successful, and, for example, in Germany, there was significant growth in the number of registered PHEV and BEV by 200% in the first half of 2020. Respectfully in the first half of 2019, the same growth amounted to 43%. EV sales in Europe are estimated to increase to between 2 million and 2.9 million units by 2022 compared to 600 thousand sold EVs in 2019. Europe’s electrical vehicles market recovered relatively quickly from the pandemic’s consequences. [12] At the beginning of 2021, electric vehicle sales in Europe reached 450 thousand. [11]

In 2020, the situation was different in the United States. Instead of promoting green mobility and encouraging citizens to adopt electric vehicles, the United

States government softens the CO2-emission targets. On top of that, the decreased demand for oil caused the oil prices to drop, making it cheaper to maintain an internal combustion engine car rather than an electric vehicle. It is expected that the number of EV sales will increase slightly to between 400 thousand and 1 million by 2022 in comparison to 300 thousand units sold in 2019. [12] However, the situation improved in the first four months of 2021, with electric car sales doubling compared to the same period in 2020. [11]

In the long term run, with the focus of the Chinese and European governments on promoting green mobility and their determination to embed electric vehicles, it is forecasted that by 2030 China will increase global EV market share to 35-50 % and Europe to 35-45%. At the same time, it is likely that the increase of the United States market share will be slower than in China or Europe and will come to 15-35% by 2030. [12]

Overall, in a decade, the electric vehicles market showed significant growth over the past ten years. In 2010, there were about 17 thousand EV’s on the roads worldwide. By 2019, the number has grown to 7.2 million. [9] Furthermore, by the end of 2020, there were 10 million electric vehicles around the world. [11] Forecasts are optimistic that the EV market will thrive.

2 Energy Load Management

The electricity demand can vary depending on multiple factors such as hours of the day, days of the week, special occasions, seasons, geographic locations, and climate. Electricity supply is based on the electricity demand levels. When the demand is at a low level, there is no shortage of available electricity. When electricity demand has peaked, the available electricity becomes not enough, and the electricity price goes up. In Europe, buildings have a share of 40 percent of the total energy consumption. [14]

Electric vehicles change the fluctuation pattern of the electricity demand since each EV has a high charging capacity. The number of electric vehicles is growing with them getting more and more popular among consumers. EV manufacturers produce vehicles with more significant battery capacities to meet consumer needs. Those factors contribute to the need to have more charging stations installed on the site to serve the demand even during peak hours.

The increase in electric vehicles and charging points worldwide poses a particular challenge on the electrical grid. Simultaneous charging of many EVs at the same charging site, for example, office buildings, supermarkets, or residential areas, will increase the risk of grid congestions and power outages. [15] Peak demand must be reduced to keep the electricity distribution process safe, scalable, reliable and prevent electricity network failures. [16]

The peak demand problem can be solved either by changing the cable, current transformers, and the main fuse to increase the network capacity on the supply side or reduce energy consumption during the peak hours. Due to the high financial costs and organizational difficulties of expanding the network capacity, managing the demand side electricity consumption is preferable. [15, 16]

Demand-side management (DSM), also commonly referred to as load management, is a concept that allows control of the load and brings down the total electricity consumption on the site. DSM systems hold energy demand in line with the supply available. Load management helps to reduce the electricity costs and improve the load factor by minimizing the possibility of power grid congestion. [17] Load management is not dedicated to saving energy but instead creates a more efficient power system by distributing energy demand overtime to avoid peak hours. [16]

2.1 Residential Loads

There are different categorization strategies for the residential loads. [16] Residential load is the amount of electricity a residence can use at any time. The most relevant for load management is the categorization of shiftable and non-shiftable loads. The electrical appliances that cannot be used at a different time, meaning that their usage cannot be shifted in time, create non-shiftable loads. Usually, vital household appliances are in this category. Such appliances can be, for example, lights, vacuum cleaners, hairdryers, and other small home appliances. Shiftable loads consist of appliances that can be used during off-peak hours. An example of these appliances would be a dishwasher or an electric vehicle. [18] Shiftable loads are sometimes called time-shiftable loads, and they play an essential role in creating load flexibility and DSM programs. [19]

2.2 Load Management in Electric Vehicle Charging

Every charging site has an individual connection capacity that inevitably limits the number of EV chargers installed on one site. Load management aims to prevent the electricity demand peak concerning the efficient capacity distribution to the charging points. It provides a possibility to install more charging stations for electric vehicles without changing the connection capacity of the site. With load management, it is possible to avoid expensive one-time connection capacity increases and prevent power outages on the site. [6]

Different strategies for electric vehicle load management fit under the various use cases.

2.2.1 Integrated Load Management

The limit of the total available power is internally configured for each charging point individually. The charging station must support Load Balancing between sockets. Integrated Load Balancing means that, for example, the charging point with two connectors can distribute the available power (22 kW) evenly between both connectors if two EV's are charging (11 kW each). Alternatively, supply all 22 kW if only one EV is charging at the moment. [20]

2.2.2 Dynamic Load Management

This load management requires a static limit that will be applied for the whole charging site. The aim is to evenly distribute available energy capacity among the charging stations on the charging site. Every charging EV gets an even share of the available power. [6]

Dynamic Load Management will suit a real-life situation where four charging stations are installed on the site, each having a maximum capacity of 22 kW. These charging points could potentially require 88 kW when all are charging with maximum power. However, the electrical installation of the site can only handle a maximum load of 44 kW.

Example 1: when all four stations are charging, dynamic load management will distribute the available capacity evenly among them, allowing each station to charge with not more than 11 kW, as shown in Figure 1.

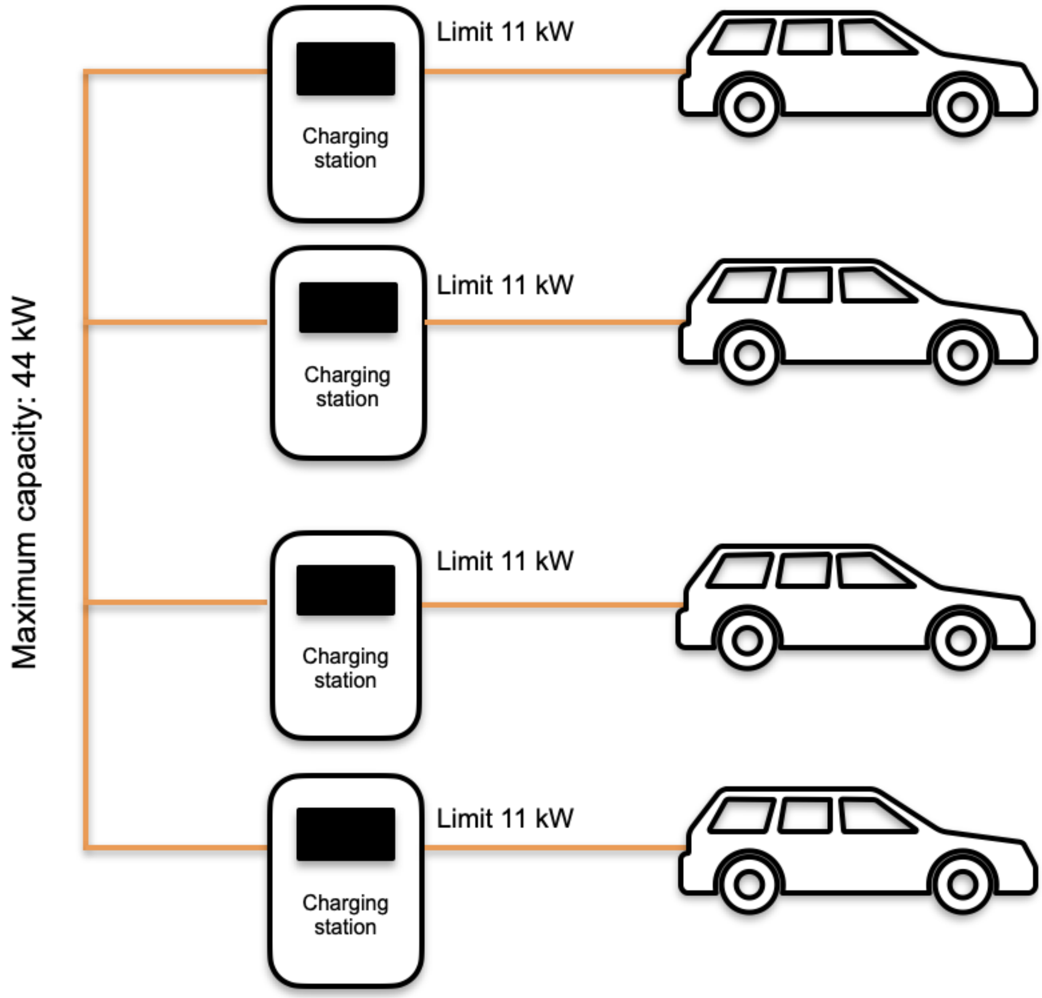


Figure 1. Dynamic Load Management example 1.

Example 2: two out of four charging stations are occupied. Dynamic Load Management distributes power among charging stations allowing each station to charge with not more than 22 kW, as shown in Figure 2.

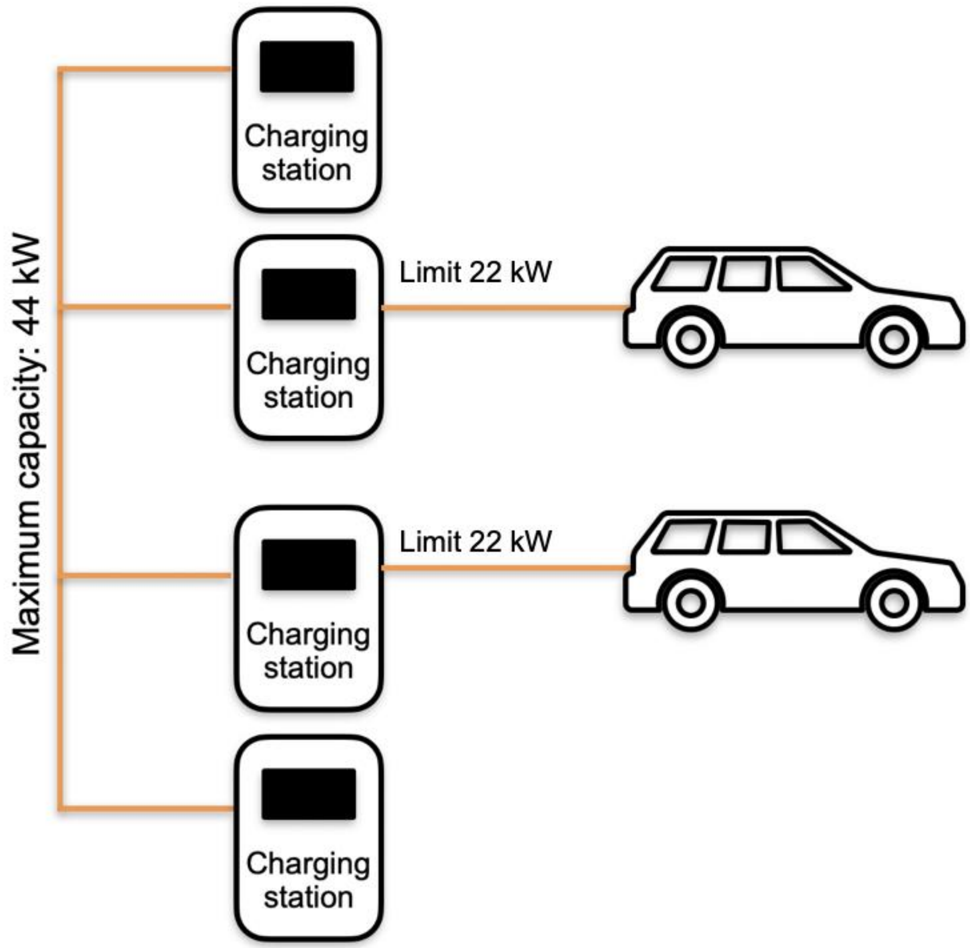


Figure 2. Dynamic Load Management example 2.

When the new electrical vehicle starts or stops charging, Dynamic Load Management recalculates and adjusts the limits of charging power per station.

2.2.3 Adaptive Load Management

The energy demand on the site can differ depending on many factors. It can happen because of time of the day, day of the week, or weather. This load balancing strategy includes measuring the total site consumption taking into consideration both shiftable and non-shiftable loads. Using the measurements, it adjusts the available charging power accounting for the total building consumption. In case that the building energy consumption increases, the total available charging power will drop to ensure that the principal connection capacity limit of the charging site will not be exceeded. [6, 21]

An example illustrated in Figure 3: when there is a maximum available capacity limit of 500 kW, the site consumption in total is 412 kW, and charging site consumption is 0 kW. The available charging capacity will be 22 kW per charging station.

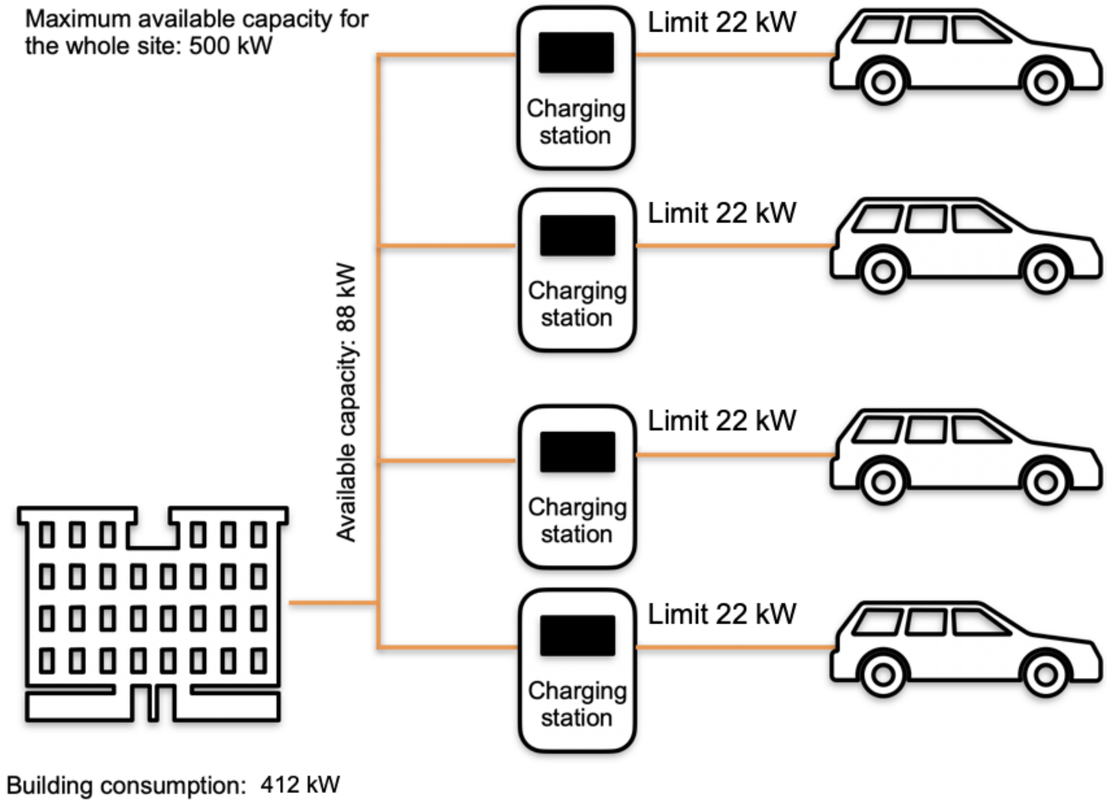


Figure 3. Adaptive Load Management during low energy consumption.

However, if the building consumption rises, as shown in Figure 4, the available capacity will be restricted for charging stations with respect to the principal connection limit.

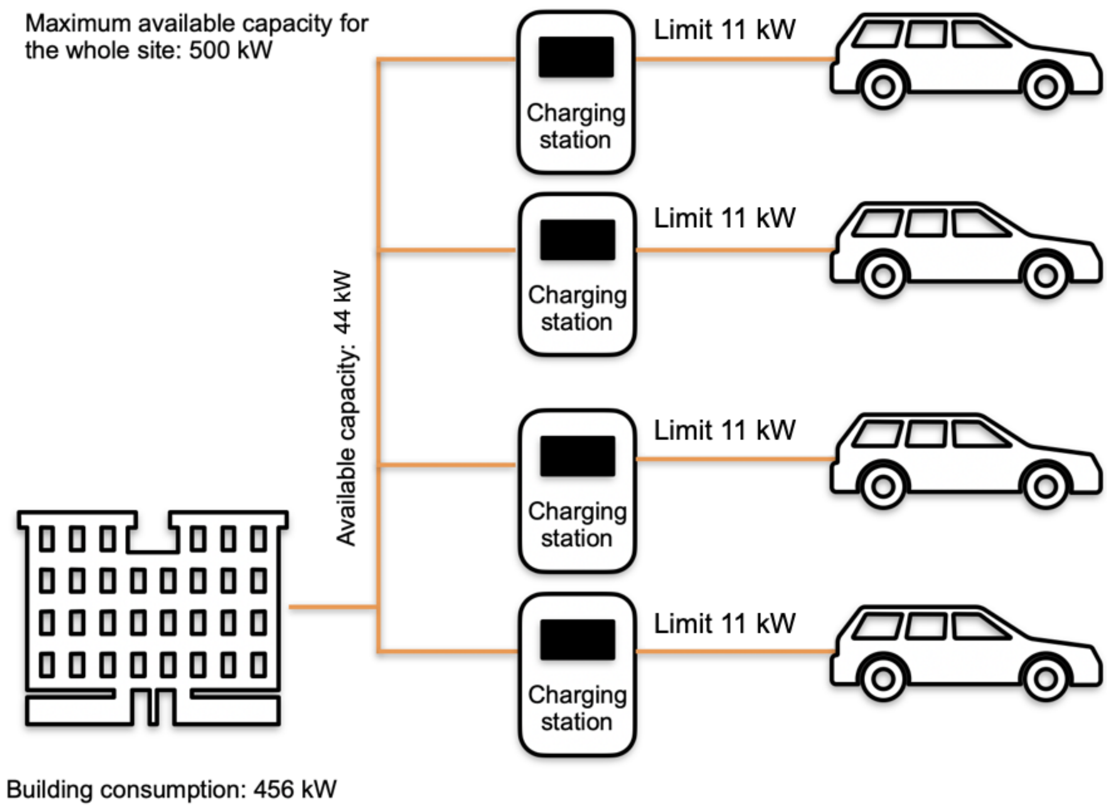


Figure 4. Adaptive Load Management during high-energy consumption.

In this example, the initial consumption of the charging site is 0 kW, and the total building consumption raised to 456 kW. The total available capacity per charging point was limited to 11 kW.

2.2.4 Time Based Load Management

This concept can also measure all the loads from the charging site. It prioritizes the distribution of available capacity per station based on the number of variables such as scheduled departure time of the electric vehicle, individual car capacity, energy limits, and specifications. [21] However, this type of load management will not be covered in this work.

2.3 Benefits of Load Management

Optimization of energy consumption on the site by controlling each charging station power output has several benefits. Load management helps to lessen electricity costs and avoid costly upgrades on the charging site. In the global overview, successful load management adaptation will help build fewer power plants for energy generation and cables for energy transmission. [17] Both customers and the charging site benefit from the fact that load management helps deploy and expand the proper electric vehicle-charging network to support increasing consumer demand in electric vehicles.

3 Competitors Analysis

This chapter will cover competitors of the Virta Dynamic and Adaptive Load Management solutions.

Load management is a trending topic nowadays. In the scope of this research, we can divide existing solutions into two categories: manufacturers' load management and load management that is interoperable with multiple charger brands.

3.1 Vendor-locked Solutions

Many charging station manufacturers implemented load management as a build-in charger functionality. Below are examples of manufacturers and their solutions.

3.1.1 Alfen

The manufacturer offers internal Load Balancing for a single charging point and Smart Charging Network supporting up to 100 charging sockets or 50 dual-socket chargers. [22, 23]

For internal Load Balancing station inspects the total available capacity and required by electric vehicle power. Innovative electronics inside the charger allocate the charging power with respect to the maximum connection capacity. Load Balancing is activated only when multiple vehicles are connected to the charge point. Charging power is equally distributed between connected vehicles. [22]

Smart Charging Network allows controlling a charger cluster. Chargers are connected via a simple IP connection using a LAN cable. The network requires an external energy meter to measure total energy consumption and load per phase. All connected charging stations communicate with each other and align charging speed. It is an independent network that knows how many chargers are connected and available. It can also detect faulty chargers and distribute charging capacity accordingly. Available charging power is evenly distributed among charging vehicles. [23]

3.1.2 Ensto

Offers Advanced Load Management features optimal distribution of power between connected electric vehicles by considering overall site consumption and individual car needs.

Advanced Load Management consists of Dynamic Load Management, Phase Aware Load Management, Round Robin Sharing Logic, and Active Load Management. [24]

- Dynamic Load Management - equal distribution of available capacity among charging EVs. It works for a single charge point as well as for the group of many stations. [24]
- Phase aware load management - considers how many phases every charger was connected to and how many phases are used during the charge. Performs phase rotation, which allows multiple EVs to charge from different phases. It ensures lower energy consumption and more capacity available on the site. [24, 25]
- Round Robin Sharing Logic - combines phase-aware load management with the individual capacity of every charging car. It allows higher than average power output to the EVs and better phase balancing on the charging site. [24]
- Active Load Management - maximum available capacity for the charger group changes depending on the total power consumption of the whole site. [24]

Ensto Advanced Load Management operates on DLM Master - DLM Slave. Each charger group has one station that acts as DLM Master and one or more stations that act as DLM Slaves. The DLM Master is configured to the maximum allowed charging power, and it commands a charging limit to the DLM Slaves. When changes happen to the DLM Slave station, they are communicated to the DLM Master, which considers them and commands a new current limit to the group of DLM Slaves. [25]

3.1.3 Other

There are other charge point manufacturers who develop integrated load management for their stations, for example, Defa [26], Keba [27], EVBOX [28], Pod Point [29], Circontrol [30], ChargePoint [31], NewMotion [32] and Blink [33].

Their solutions differ in advancement. However, all of them have one main downside: they can work only for the chargers of the same brand.

3.2 Non-vendor-locked solutions

Companies that created platforms for charging station management offer different energy management tools and solutions that fit chargers of multiple brands.

3.2.1 GridX

Offers XENON platform and an embedded system called gridBox to manage distributed energy resources. XENON charge solution offers Dynamic Load Management in real-time with gridBox controller. GridBox runs load management services, collects, and reports data to the cloud. GridBox supports multiple charger brands and can locally manage energy flows for up to 10 days by replacing the Central Management Platform. Additional functionalities include prioritizing charging stations, expansion by adding batteries and other energy resources, data analyses, and export and user notifications. [34]

3.2.2 Driivz

Platform compatible with over 170 charger models. Driivz SmartChain™ Energy Manager is a software package that offers energy demand response functionality. It supports chargers, including Vehicle-to-grid (V2G) and batteries. The solution balances charging loads and helps to avoid peak hours of energy demand. [35]

3.2.3 The Mobility House

ChargePilot is independent of the charge point’s manufacturers system that provides charging stations and energy resources management. Depending on customer needs, the company offers Static Load Management with even distribution of available power among charging EVs, Dynamic Load Management that adjusts available charging capacity with respect to total building consumption, and Timetable-based Load Management distributes charging power based on travel timetables. The Mobility House solution uses its own Smart Charging Controller, detects actual charging power of the EVs, including asymmetrical phase load, supports an unlimited number of charging stations, is resistant to internet connection interruptions, features alert messages, and prioritization of charging stations. [21]

3.2.4 Vattenfall InCharge

The platform supports chargers of multiple brands. It provides a delayed/timed start-stop charge solution regulating or stopping EV charges during peak hours. Stations start charging either at a particular time or when electricity rates are cheapest.

Additionally, offers Active Load Balancing, which monitors the real-time load and adjusts charging capacity accordingly. [36]

3.2.5 Foremica

The company offers hardware solutions for home and property energy management. The smart device collects energy-related data on the property and balances EV charging by performing advanced load management. It is a manufacturer-independent system that supports about 150 different charger models. One Foremica device supports up to 100 chargers. [37]

3.2.6 GreenFlux

The company provides a cloud-based platform for charger management and an intelligent charging solution supporting chargers of multiple brands. There is no limit to the stations that can be connected. It offers a load management solution with dynamic power distribution based on the available grid capacity. [38]

3.2.7 Other

More companies offer electric load management to their customers, for example, Last Mile Solutions [39], and Jet Charge [40].

3.3 Virta's Solution

Virta offers a cloud-based platform for EV chargers and energy management. Virta innovative charging solutions support load management with static and dynamic limits for multiple charger brands. New charger models are integrated into the platform regularly. Adaptive Load Management solution works with additional hardware module that has to be installed on the charging site. It is also resilient to network connectivity issues. Virta platform provides comprehensive analytics to customers about energy usage and charging consumption at any given point in time. Improvement of current energy management solutions continues regularly.

4 Theoretical Background of Electric Vehicle Chargers

This chapter will hold a brief explanation of electric current and the difference between AC and DC charging.

4.1 Electric Current

Electric current can be transmitted in two ways: alternating current (AC) and direct current (DC). Direct current always flows in the same direction and at a constant rate, while alternating current reverses direction and changes its magnitude. [41]

Power plants generate alternating current. It always comes from the grid, transmitted via power lines. Most of the standard electrical outlets in Europe have alternating current of 230V and 50 Hz. In comparison with direct current, alternating current can be used over longer distances with less loss. [42]

All batteries, including electric vehicle batteries, can be charged only with direct current. Batteries store energy by converting DC into chemical energy. They are designed only to allow the flow of electrons in a single direction from the anode to the cathode. Therefore, batteries can only use and release direct current. [43]

4.2 AC Charging vs DC Charging

Electric Vehicles have built-in batteries inside to store energy. When using alternating current to charge an EV, the on-board charger of the car is used to convert AC into DC that can deliver energy to be stored by the car battery. DC charging, which is also commonly referred to as fast charging, does not involve the on-board charger in the process because the station itself does the current conversion. It enables sending current directly to the car battery via Battery Management System. DC charging can be much faster than AC charging because the on-board charger does not limit it. This difference is illustrated in Figure 5.

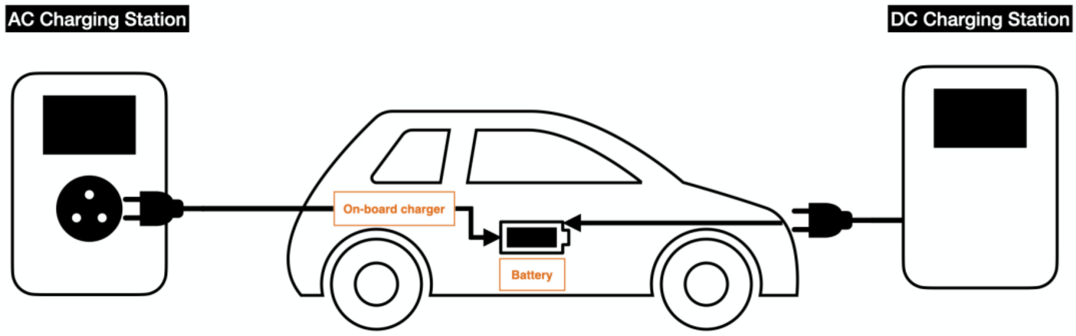


Figure 5. Difference between AC and DC charging.

However, since the DC chargers are expensive, there are more AC chargers available to consumers. [42]

Voltage also needs to be considered when charging an EV. The combination of charging current and voltage will determine the rated power. There are different types of charging: single-phase AC, three-phase AC, and DC fast charging. One phase AC charging means a standard single-phase 230V supply that will give the car a maximum power of 7,4 kW. Three-phase AC charging requires a 400V connection to the grid. Rated power will be a maximum of 22 kW or 43 kW. On the other hand, DC charging can have greater charging power of 50-120 kW. [44]

5 Charging Networks and Infrastructure

An EV charging network allows operators to receive real-time data about their charging station and control charging status. It enables dynamic pricing, payment processing, and identifying faults instantly.

Charger network management software collects the data from the power meter and other sources of information built in the charging point and communicates it to the Charging Station Management System (CSMS). CSMS facilitates, on the customer side, services such as billing, user authentication, and payment. It also helps the site host set pricing, adjust the EV chargers' configuration, and use data to learn more about consumer charging habits and expectations. [45]

Charging stations can be designed to operate individually, requiring no connection to the central management system. These EV chargers are called Non-Networked Stations because they cannot be accessed and managed remotely. Without sophisticated communication features, non-networked EV charging stations are not connected to the internet and have limited charging functions. [46] In this scenario, the station merely performs the duty of transmitting energy to electric vehicles without any additional station access or control. [47]

The charging point intended to be a part of the charging infrastructure is called a Networked Station, and it can be remotely controlled. Via cable or wireless, networked EV charging stations are linked to the internet and can communicate with an Electric Vehicle Service Provider (EVSP) backend system. This connection allows station owners or site operators to control who can use stations and regulate how much it costs drivers to charge their vehicles. Typically, an EVSP maintains a networked electric vehicle supply equipment (EVSE) group. EVSP can use its networking ability to communicate directly with drivers or other EVSPs. The information about real-time charge point status, system functionality, and location can be collected, stored, and shared, making charging station management more effective and efficient. [46]

5.1 Charging Networks

Charging stations can be non-networked, open-networked or closed-networked. [45]

Non-networked chargers do not have a connection to any network. This option is suitable for charging point owners who seek a cost-effective and basic solution. It is typically used in single-family residences. [45]

In **closed networks**, to establish a connection between the EV charging station and network server, proprietary communications protocols are used. Customers are locked on using only the manufacturer network’s software and compatible hardware. [45]

Open networks use open standard protocols to enable the owners of compatible charging stations to link them to the various open networks. This connection allows running various networking providers on the same charger avoiding significant updates to existing hardware. Also, the possibility to connect charging stations from different manufacturers to one managing platform appears. [45]

5.1.1 Open vs Closed networks

The main advantage of implementing proprietary charging networks is absolute control over all the charging system elements. The most significant disadvantage of the closed networks is vendor lock-in, which means that owners of charging stations must use only the vendor’s charging infrastructure and hardware.

Open networks offer flexibility in allowing owners to connect different complying charging stations to multiple networks. Open networks promote interoperability. In the electric vehicle-charging infrastructure, interoperability means the connectivity of critical infrastructure elements such as electric vehicles, charging stations, charging networks, the grid, and the software system that allows these elements to operate smoothly and reliably together. Open Charge Point Protocol (OCPP) is one of the standardized protocols to create Open Networks. [45]

Some EV charger manufacturers develop a way for fast network chargers to be integrated into the management platforms that operate on Open Charge Point Protocol. For example, Easee and Innogy manufacturers provide a custom application-programming interface that accepts OCPP defined commands. When received, these commands will be processed and converted to the manufacturer-specific commands inside the manufacturer cloud.

5.2 Open Charge Point Protocol

OCPP enables interoperability between electrical vehicle chargers and charging station management systems and defines standards of data exchange. OCPP is widely used and is being promoted by Open Charge Alliance since 2009. The main advantages of OCPP are free usage and widely adopted open-source standards. [45]

Open Charge Point Protocol does not require the usage of any specific communication technology. The only requirement is that the technology of choice supports Transmission Control Protocol / Internet Protocol (TCP/IP) connectivity.

Development of the first version of Open Charge Point Protocol started in 2009 and was published in 2010. Since that time, the protocol has evolved and was improved by Open Charge Alliance. Today there are three main versions of OCPP.

5.2.1 OCPP 1.5

This version uses the Simple Object Access Protocol (SOAP) framework for communication, which allows messages to be transmitted over the Internet between components. The protocol supports 10 operations initiated by the charging station and 15 operations initiated by the Central System, making 25 supported operations. [48]

5.2.2 OCPP 1.6

This protocol version includes all functionalities of version 1.5. It has newly developed support for JavaScript Object Notation (JSON) - lightweight data-interchange format. Load balancing is made possible with Smart Charging support and the use of charge profiles. Smart Charging enables the central system to control the charging power of a single unit or entire charge point. OCPP 1.6 provides more statuses for the charging points in comparison with version 1.5. [49]

5.2.3 OCPP 2.0.1

The newest version, entirely based on JSON. Compared to OCPP 1.6 has improved functionalities in device management, transactions, security, and smart charging. It supports of ISO 15118 standard featuring plug-and-charge and bi-directional charging and discharging of EVs. [50]

5.3 Charging Infrastructure

The core of charging infrastructure typically consists of Charging Station Management System, Charging Station and Electric Vehicle as illustrated in the Figure 6. [51]

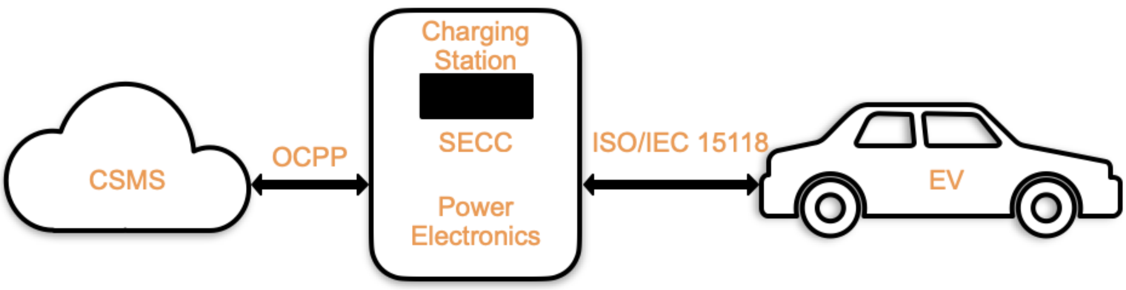


Figure 6. Basic charging infrastructure.

A charging station represents a physical device where an electric vehicle can be charged. It can have one or multiple connectors. The charging point is responsible for both way communication with EV and both way communication with CSMS. There is a communication between Supply Equipment Communication Controller (SECC) and the power electronics within the charging station.

5.3.1 Charging Station and Electric Vehicle - Connection

Physically the charge point connects to the electric vehicle with the help of connectors and vehicle inlets. Sub-organization SC 23H “Plugs, Socket-outlets and Couplers for industrial and similar applications, and for Electric Vehicles” belong to the International Electrotechnical Commission (IEC) committee defines and maintains standards for different types of connectors for electric cars.

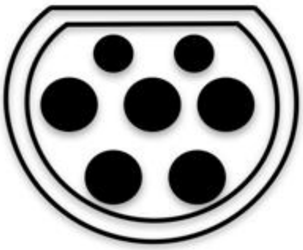
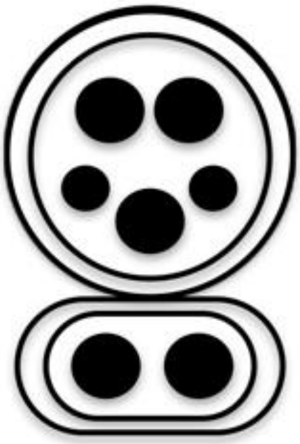
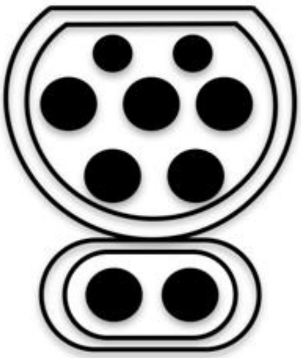
According to the IEC 62196 standard, there are four main types of connectors: type 1 (slow AC charging), type 2 (slow AC charging), COMBO 1 & 2, also called Combined Charging System (CCS) (slow AC and fast DC charging), type 4 called CHaDeMO. [52]

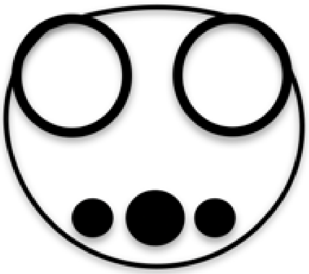
Apart from the main types, there are also Tesla SuperCharger for fast DC charging, Schuko or a simple household outlet for slow AC charging, and own Chinese standard for charging connectors (similar to Type 2 connectors).

Connector type depends on the geographical region where the charging station is located and the charging, i.e., AC or DC charging, as illustrated in Table 1.

Table 1. Different charging connector types.

	Outlook	Charging type	Region
Type 1		AC	US/Japan

Type 2		AC	Europe
CCS type 1		AC & DC	US/Japan
CCS type 2		AC & DC	Europe
CHaDeMO		DC	US/Japan

Tesla SuperCharger		DC	All
Schuko		AC	All

Tesla SuperCharger and Schuko are used worldwide, whereas North America, Japan, and Europe adopted different types of connectors. Type 1 and CCS type 1 connectors are primarily used in North America and Japan, while type 2 and CCS type 2 connectors are adopted across Europe. [53]

5.3.2 Charging Station and Electric Vehicle - Communication

Charging communication, however, is not dependent on the geographical position and is unified across the globe. The communication consists of Low-level Communication (LLC) and High-level communication (HLC).

Charging communication is started by introducing an electric vehicle and a charging station via basic signalling of low-level communication. Two communication pins inside the charging connector are responsible for basic signalling: proximity pilot pin and control pilot pin.

The proximity pilot signal allows the electric car to determine if it is plugged in: the proper connection is established between the charging connector and the car inlet. In case that the connection is established poorly or not at all, the charging will not start, and the whole process of charging communication will be stopped because of safety reasons.

The control pilot pin gives an option to limit the charging current. The SECC in the charging station constantly generates the pulse-width modulation (PWM) signal, and the control pilot pin immediately sends it to the EV. In this way, the EVSE informs the car's on-board charger about the maximum available current that can be requested from the charging station to the car. The car can request needed current from the charging station as long as the value is lower than the set maximum current. [54] [55]

The second level of communication between the charging station and the car is high-level communication via Power Line Communication (PLC). PLC is a technology that enables the communication of data over the electrical cables in a half-duplex manner. It allows one-direction transmission at the given moment. Power Line Communication is adopted by the ISO/IEC 15118-series standard, which describes the communication interface between EV and charge point based on Open System Interconnection (OSI). [56] OSI is a conceptual seven-layer model that defines characteristics and standards of the communication between diverse communication systems. HLC in the electrical vehicle charging is used for transferring complex information such as battery model, remaining charging time, state of charge, and charging parameters, and that can be used for multiple services, including load balancing. [57, 58]

The general sequence of the charging process can be described with the following steps [54]:

1 The supply equipment communicates that there is power.

2 Electric vehicle detects the charging station plug via the proximity pilot pin.

3 With the help of the control pilot pin, supply equipment detects that the EV is plugged in and communicates the ability to give energy and the level of available current to the vehicle.

4 Electric vehicle controls the energy flow and the number of current phases that will be used during the charging session.

5 Electric vehicle determines how long the charging session will continue.

6 The charging session can be stopped either by unplugging the EV or by command from CSMS or by EV.

5.3.3 Charging Station and Central Management System - Connection

The number of parameters should be met to establish and maintain the connection between the charging station and Central Management System. In this research, we will cover the basics for connection and communication based on OCPP-J.

In the connection between a Charge Point and a Charging Station Management System (CSMS) using OCPP-J, the CSMS acts as a WebSocket server, and the Charging Station acts as a WebSocket client. [59]

The charging station connects to the server with WebSocket protocol and provides a Uniform Resource Locator (URL) that contains the Charging Station's unique identity. URL example: ws://cms.example.com/ocpp/STATION_IDENTITY. [59]

5.3.4 Charging Station and Central Management System - Communication

Inside WebSocket connection charger and server exchange request/response messages that contain OCPP commands. After one sends the request (**CALL**), it is waiting for the response (**CALLRESULT**) or error message (**CALLERROR**). [59]

Communication starts with a “BootNotification” **CALL** from the charger to the server to indicate that the charger is powered up. [59]

CALL message always includes:

- *MessageTypeId* - number to identify the message type
- *MessageId* - identifier to match request and result
- *Action* - a string that identifies the action that is required on the other side
- *Payload* - JSON payload as the arguments to the Action.

The syntax is like this: `[<MessageTypeId>, "<MessageId>", "<Action>", {<Payload>}]`

Example of BootNotificationRequest is in Listing 1:

```
[2,
 "19223201",
 "BootNotification",
 {
  "reason": "PowerUp",
  "chargingStation": {
      "model": "SingleSocketCharger",
      "vendorName": "VendorX"
  }
} ]
```

Listing 1. BootNotificationRequest.

CALLRESULT always includes MessageTypeId, MessageId and a payload, containing the response to the *Action* in the original **CALL**. [59]

The syntax is like this: [<MessageTypeId>, "<MessageId>", {<Payload>}]

Example of *BootNotification* response is in Listing 2:

```
[3,
 "19223201",
 {
   "currentTime": "2013-02-01T20:53:32.486Z",
   "interval": 300,
   "status": "Accepted"
} ]
```

Listing 2. BootNotification.

CALLERROR can be sent when the error occurs during the message transport or message contains invalid data. It always includes five elements: MessageTypeId and MessageId, an errorCode string, an errorDescription string, and an errorDetails object. [59]

The syntax is like this: [<MessageTypeId>, "<MessageId>", "<errorCode>", "<errorDescription>", {<errorDetails>}]

Example of CALLERROR message is in Listing 3:

```
[4,
  "162376037",
  "NotSupported",
  "SetDisplayMessageRequest not implemented",
  {}
]
```

Listing 3. CALLERROR.

6 Requirements, Implementation and Testing

This chapter covers an overview of system infrastructure, business and technical requirements for Dynamic and Adaptive Load Management solutions, implementation, and testing.

6.1 System Architecture and Infrastructure Overview

Both Load Management solutions are implemented inside the cloud platform called Energy. Energy does not control electric vehicle chargers directly.

Chargers are controlled by a service called “ChargersHub”. ChargersHub is a system that consists of OCPP servers that communicate directly with chargers. It also has different services and middleware that allow external software to exchange information and control charging points. Energy services communicate to ChargersHub via Virta Core API.

Energy platform utilizes microservice architecture - it represents a cluster of different services with individual logic and a single function. Internally services communicate with each other via HTTP API requests. External communication may happen via API calls or real-time events arriving to the Redis - Remote Dictionary Server - queue. Each service works in the Docker container, which is an isolated and self-sufficient executable software package. In order to manage, scale and deploy containerized Energy software, Kubernetes is used.

Energy platform uses React.js - JavaScript front-end framework - for building user interfaces, the back end part is implemented with Node.js and Express web framework for Node.js is used. The storage of data is managed via object-relational database PostgreSQL and time-series SQL database TimescaleDB. Database querying is done using SQL query builder - Knex. The system also utilizes Redis for a real-time chargers events queue and caching.

6.2 Dynamic Load Management

This section covers requirements, logic flow, technical decisions, and testing methodologies used during the Dynamic Load Management solution implementation.

6.2.1 Requirements

The customer adds charging stations into the dedicated groups. The number of chargers in the group is not limited. Each group has an individual limit set by the customer that represents the maximum available charging capacity distributed to the chargers. The total power consumption of the group cannot exceed the user set limit. Group maximum power limit needs to be distributed evenly among all charging stations.

6.2.2 Charging Station Requirements

Dynamic Load Management solution can be applied to the charging station models that passed Energy DLM integration and, therefore, supported.

There are specific requirements that charging station should meet in order to be compatible with Dynamic Load Management functionality:

- Operate on OCPP JSON 1.6
- Support functionality of dynamically changing maximum current output given to the car

Currently, the Energy platform supports adjusting current with either Change Configuration or Set Charging Profile OCPP commands.

Change Configuration command allows Central Management System to request a configuration parameter change from the charge point. Parameters can include different configuration keys with respected values. CMS sends a changeConfiguration request to the charger. The request contains a key-value pair where the key represents the configuration-setting name, and the value is a new setting. However, in the scope of DLM, we only use this command to change the offered by charger value of current. Different charging station vendors introduce different keys for charging the current.

The payload of the changeConfiguration request applicable to the stations manufactured by Alfen vendor is in Listing 4:


```
{ "Connector1-MaxCurrent": "16" }
```


Listing 4. ChangeConfiguration payload.

By requesting charging stations to set charging profiles, CMS can affect charging current or power. This request can be executed with the Set Charging Profile OCPP command. There are three charging profile purposes in the OCPP documentation: ChargePointMaxProfile, TxDefaultProfile, and TxProfile. In the scope of the DLM solution, we are using only TxDefaultProfile.

The payload of the setChargingProfile request applicable to the stations manufactured by Circontrol vendor is in Listing 5:

```
{
    "connectorId": 0,
    "csChargingProfiles": {
        "chargingProfileId": 200,
        "stackLevel": 0,
        "chargingProfilePurpose": "TxDefaultProfile",
        "chargingProfileKind": "Absolute",
        "chargingSchedule": {
            "chargingRateUnit": "A",
            "chargingSchedulePeriod": [
                {
                    "startPeriod": 0,
                    "limit": 16
                }
            ],
            "startSchedule": "2021-04-06T12:26:51.329Z"
        }
    }
}
```


Listing 5. SetChargingProfile payload.

TxDefaultProfile can alter the stations charging current during the ongoing charge. The current value can be adjusted per charger connector.

A list of currently supported by DLM solution chargers can be found in Appendix 1.

6.2.3 User Interface

To utilize the DLM solution Energy platform user has to create a group and add all the charging points that need to be limited. In the group overview user can enable DLM functionality and set the maximum total charging limit for the group, as shown in Figure 7.

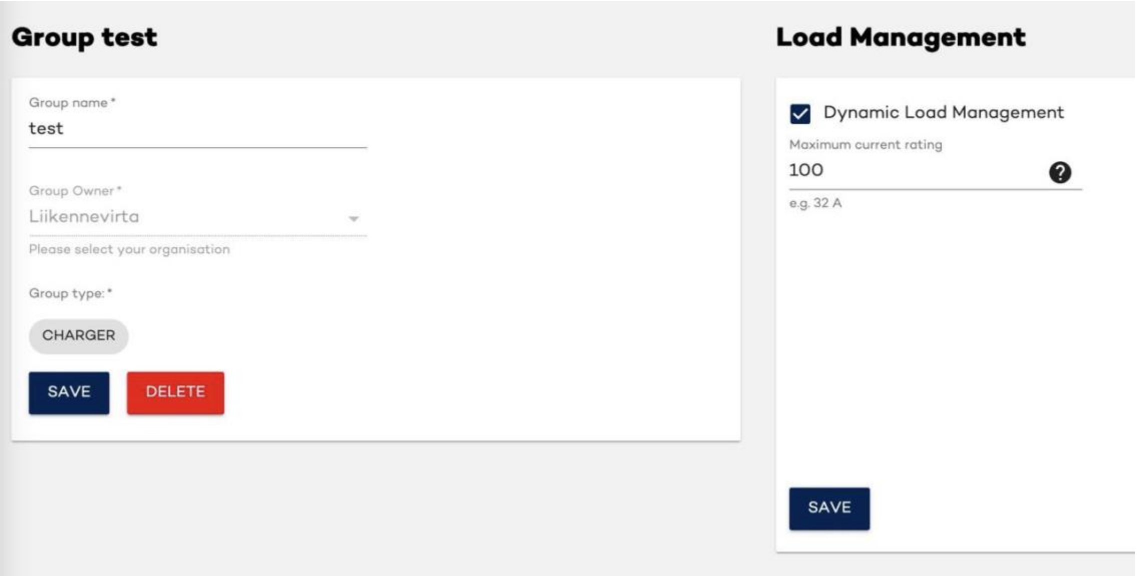


Figure 7. Group overview with Dynamic Load Management settings.

Specifying the maximum charging capacity limit is possible in the field “Maximum Current Rating”, the value must represent the desired number of amperes.

Each charging station has an indicator in the UI that shows if DLM can be applied to it or not, an example is shown in Figure 8.

Figure 8. Indication of energy management features support.

For user convenience, the group overview also features a graph of total energy consumption per current phase reported by the chargers in the group. An example of such a graph can be found in Figure 9.

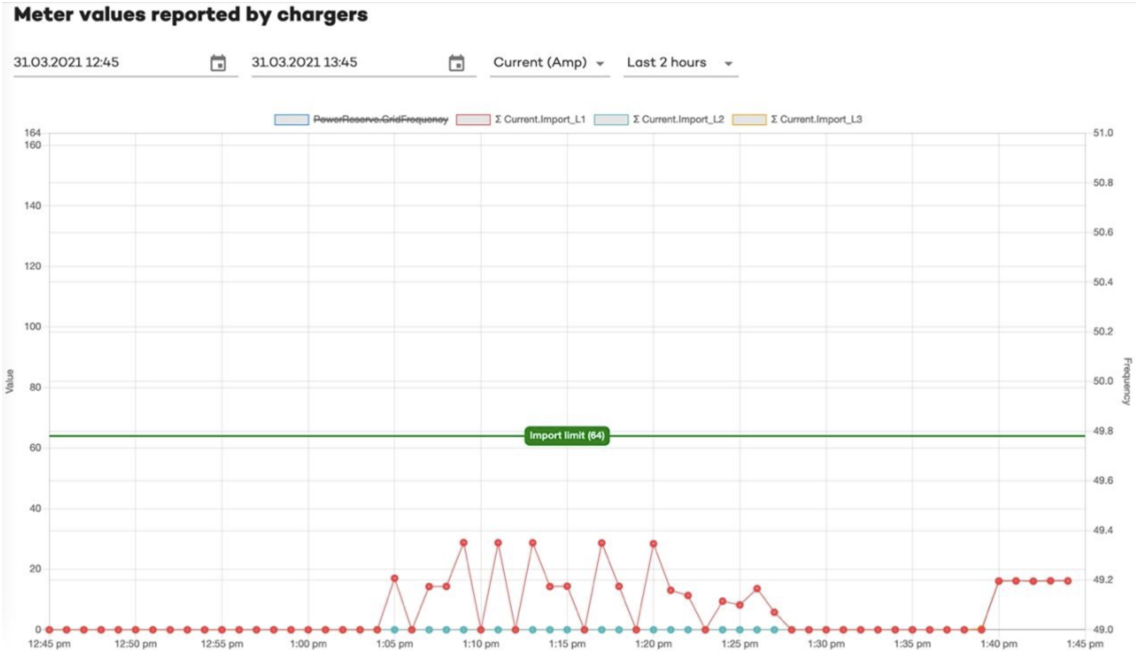


Figure 9. Total current consumption reported by chargers.

Graphical representation makes it easy to verify that total charger's energy consumption did not exceed the maximum current limit (shown as a green import limit on the graph) at any point in time.

6.2.4 User Interface Implementation

User Interface was implemented with React.js library. Components were built with the help of the Material-UI framework. The code is written in JavaScript programming language in the separate React class component. ECMAScript 6 JavaScript standard is used.

An example of the React class component is in Listing 6.

```
class Dlm extends React.Component {
  constructor(props) {
    super(props);
    this.state = {importLimit: ´´};
  }

  render() {
    return (
      <div>
        <h1>Example</h1>
        <h2>Limit is {this.state.importLimit}.</h2>
      </div>
    );
  }
}
```

Listing 6. React class component.

Dynamic Load Management component manages local state object to hold the value for the “Maximum Current Rating” field. In order to get existing value from the PostgreSQL database, the JavaScript Fetch API is used. The request to fetch data is sent during the componentDidMount() lifecycle stage of the component. New values set by the user are saved to the database upon the "Save" button click, which triggers HTTP POST request.

Example POST request implementation is in Listing 7.

```
async function postData(url = '', data = {}) {
  const response = await fetch(url, {
    method: 'POST',
    headers: {
      'Content-Type': 'application/json'
      },
    body: JSON.stringify(data)
 });
 return response.json();
}
```

Listing 7. Example HTTP POST request implementation.

New values set by the user are passed in the body part of the request.

Graphs for charger’s energy consumption are made with the help of npm (package manager for the JavaScript programming language) package called “chart.js”. For using this package in React environment, React wrapper for chart.js is used. Graphs are fetched once in a minute to display new values. It is done with the help of the setInterval() method.

6.2.5 Logic Implementation

Main part of the DLM logic is running in one microservice called “energy-dlm”. Three other microservices are also involved in the solution.

Dynamic Load Management recalculation logic can be triggered either by user actions when updating values in the Energy platform UI or by the charging station sending an OCPP message with the status update. The logical flow is described in Figure 10.

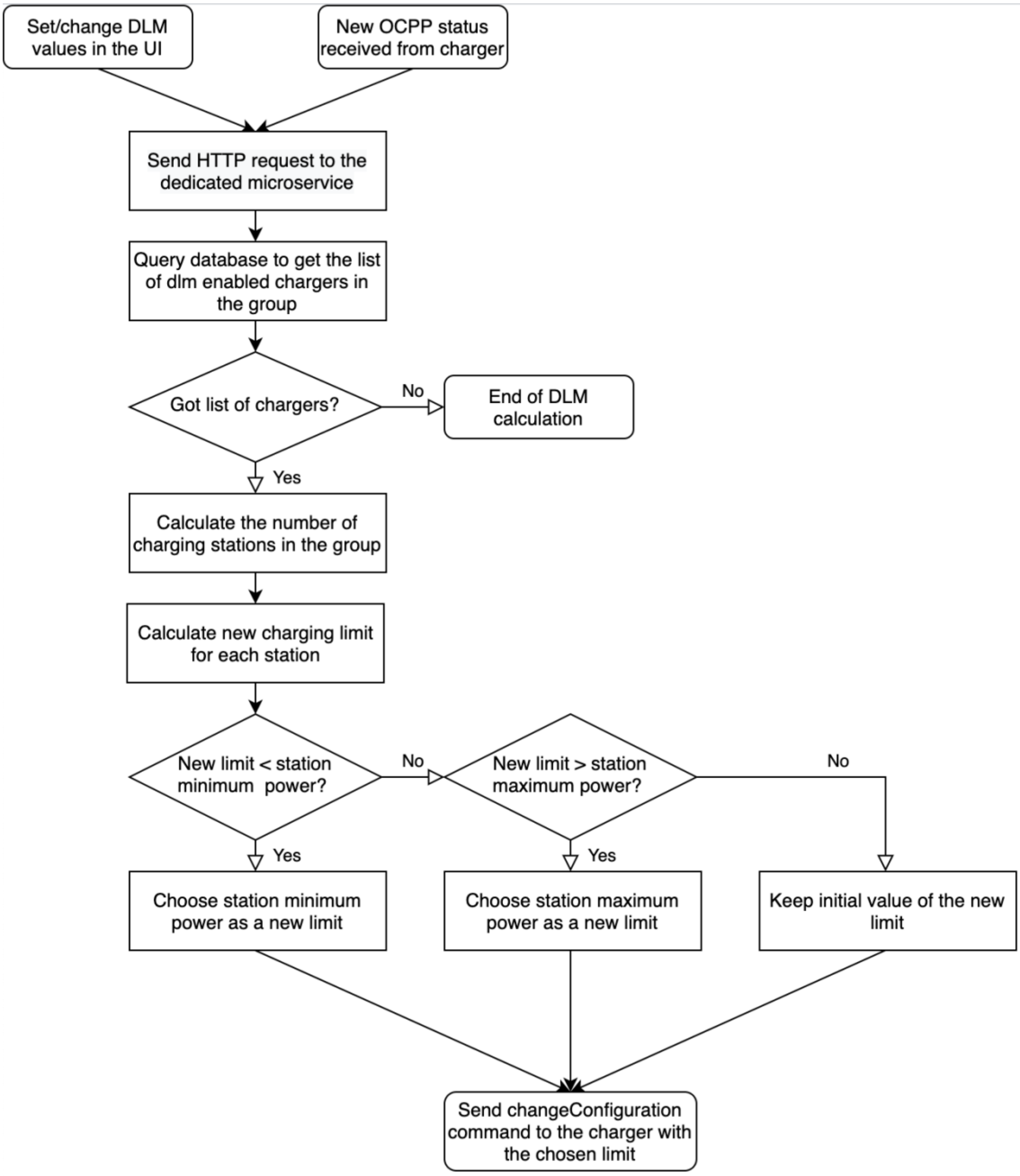


Figure 10. Dynamic Load Management logic flowchart.

The sequence of events is like this:

1 If the user changes the settings, values in the UI and clicks button “Save”. Microservice responsible for the UI processes the values and sends an

HTTP POST request to the microservice responsible for saving values to the database and other server-side interactions.
Upon saving new values to the database, an HTTP POST request is sent to the “energy-dlm” microservice.

2 If the station sends an OCPP message with a status update, it is saved in the Redis queue, shared across all Virta systems.
In Energy platform, a dedicated microservice picks items from the queue, sorts them and stores in different key-value pairs inside separate Redis instance.
When picked item contains a status update from the charger, the system checks that status value is included in the list of DLM statuses: ‘Charging', ‘Available', ‘Occupied', ‘Finishing', ‘SuspendedEVSE’ or ‘SuspendedEV’ and sends HTTP POST request to the “energy-dlm” microservice.

3 Microservice sends a joint query to the PostgreSQL database to check if the station belongs to the group with enabled DLM functionality and fetch the stations, charging power limits, and DLM settings.

4 Fetched data is used to calculate the new charging limit per station.
The total allowed current limit on the site is divided by the number of active stations in the group to get the current limit per charger. The station is considered active by the system when OCPP status is “Charging” which indicates an ongoing charging session.

5 The current limit per charger then is compared to the maximum charging power in kW and minimum charging power in kW of the charger. Those values are individual for every station. The algorithm chooses what is more: calculated limit or minimum charging power of particular charger and applies chosen value. The same logic applies to the maximum power of the charger, but the lower value is selected.
Maximum and minimum charging power values are in kW. Since described comparison is performed in amperes, we need to convert these values. Conversion formula: is (Power in kW * 1000) / 3 / 230. In this formula, we take value in kW, multiply it by 1000 to convert into watts, divide by 3, representing phases of charging and 230 volts, which is a nominal value of voltage across Europe.

6 The chosen current limit is applied to all active stations individually via the changeConfiguration command.
The request example is in Listing 8.

```
await coreApiClient(‘example/stationId/changeConfiguration', {
    method: 'POST',
    body: JSON.stringify({key: currentLimit}),
    headers: {
     Authorization: ‘Bearer token'
      'Content-Type': 'application/json',
    },
  });
```

Listing 8. ChangeConfiguration command.

Since the Energy platform does not directly connect to the OCPP server, it sends the command to charger-hub via core-api.

6.2.6 Testing

Dynamic Load Management tests were done systematically and iteratively during the solution development. For all the tests, actual charge points, and cars were used. The most recent test scenarios and actual results can be found in Appendix 2.

For the tests presented in this thesis, EV box Gen4 and Alfen charge points were used. As well as three cars: Nissan Leaf, Nissan NV200, and Tesla Model 3. The maximum current rating was set to 16 A during tests.

Tests verify that one active charging station was allowed to use maximum charging power. When the second charge point started to charge, available capacity was distributed evenly between both charging points. When the third car began charging, available capacity was distributed evenly, and stations were set to charge with minimum charging power. Tests include the case when one car stops charging and leaves.

The most recent test scenarios with expected behaviour and results can be found in Appendix 2.

6.3 Adaptive Load Management

This section covers requirements, logic flow, technical decisions, and testing methodologies used during the Adaptive Load Management solution implementation.

6.3.1 Requirements

Just like in the Dynamic Load Management solution, the customer adds charging stations into the dedicated groups. Any number of charge points can be connected to the group. Upon connection to the group, chargers receive OCPP changeConfiguration command with a list of meter values supported by the station. Meter values are needed for the real-time monitoring of the charging power. Each group has multiple limits that the customer sets. Adaptive Load Management dynamically distributes power to the charging stations depending on changes in real-time. Additional hardware on the site is needed to monitor power consumption. The main goal is not to exceed the maximum available capacity on the site with respect to the external loads. Additionally, the total energy consumption of charging points cannot exceed the maximum current rating value specified by the user.

6.3.2 Charging Station Requirements

In addition to the requirements set by the DLM solution, charging stations also must be able to report specific meter values. In order to calculate real-time consumption, each charger must send values of current per phase with not more than 60 seconds interval.

A list of currently supported by ALM solution chargers can be found in Appendix 1.

6.3.3 Additional Hardware Used

Branded hardware kit called Virta Box is used on the charging site; it is shown in Figure 11. It can be installed, for example, inside the distribution cabinet.

Figure 11. Virta Box components.

The hardware module consists of:

1 Cloud gateway
The device reads values from the energy meter via Modbus data communication protocol and transfers them to the Virta cloud via the internet. The server connection is possible via GSM/3G networks.

2 Energy meter
The device measures energy consumption data on the site and records them to the Modbus registers. Capable of measuring current up to 5 amperes.

3 Plastic cover

4 Current transformers
Current transformers are connected to the energy meter to read current values that are bigger than 5 amperes. The energy meter supports a maximum 1:1000 conversion ratio, which means that it can measure currents up to 5000 amperes with transformers.

5 Cloud gateway GSM (Global System for Mobile Communications) antenna

6 Current transformer cabling
The energy meter needs a 3-phase supply to record data of all the phases of current.

6.3.4 User Interface

Adaptive load management requires additional settings to the DLM solution. The first step is group creation. Next user must connect charge points to the group. Upon the connection, required meter values are configured per station.

Both DLM and ALM must be enabled for the group to configure additional settings. They are shown in Figure 12.

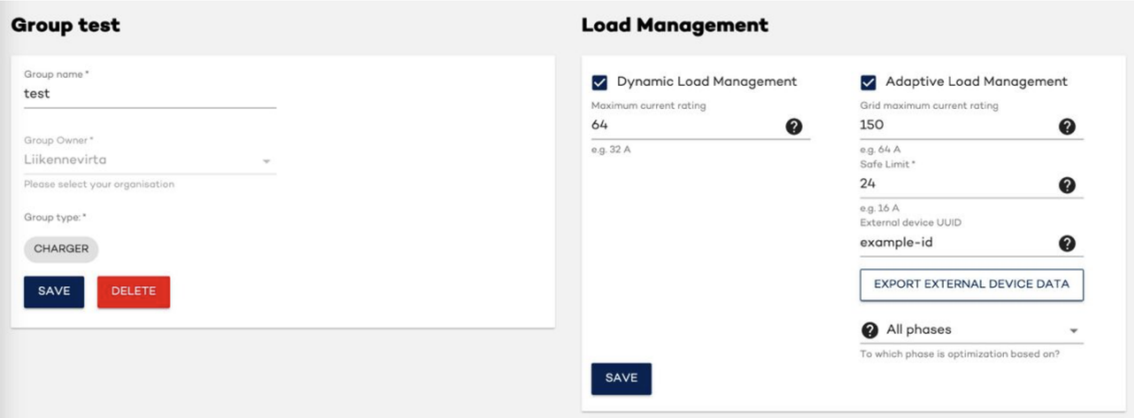


Figure 12. Group overview with Adaptive Load Management settings.

Adaptive Load Management specific settings include:

- **Grid maximum current rating** - maximum current limit that grid connection can handle without blowing fuses.
- **Safe limit** - the static limit that acts as a maximum current limit when the cloud platform stops receiving new values from the power meter due to, for example, network connection issues.
- **External device UUID** - a unique identifier that is used to connect a power meter to the group.
- **All phases (other options: 1st phase, 2nd phase, 3rd phase)** - the Dropdown menu allows choosing if the optimization is based on the highest value of all three phases of current or the value per selected phase.

By clicking on “Export external device data”, the user can download CSV (Comma-separated values) data sheet with values reported by the power meter for the selected period.

Additionally, to the graph of energy consumption reported by changers described in the Dynamic Load Management chapter of this thesis, ALM also features meter values reported by a measurement device graph shown in Figure 13.

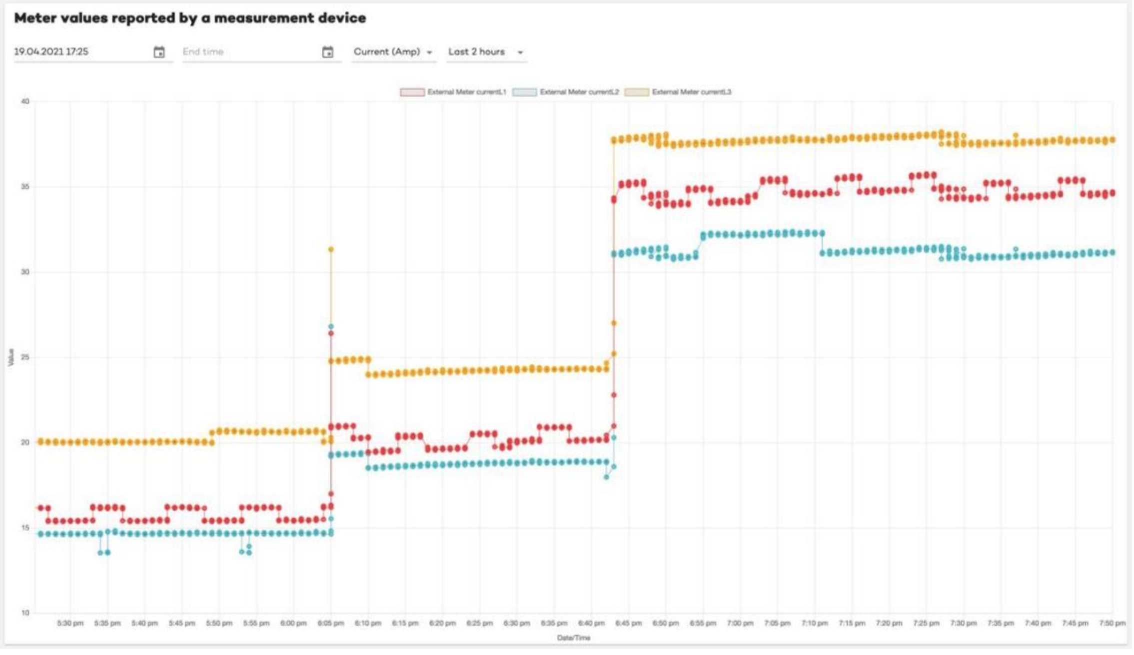


Figure 13. Total current consumption reported by power meter.

The graph shows values for all three phases of current reported by the power meter for the selected period.

When ALM functionality is enabled, the group overview also shows a widget with real-time values reported by the power meter shown in Figure 14.

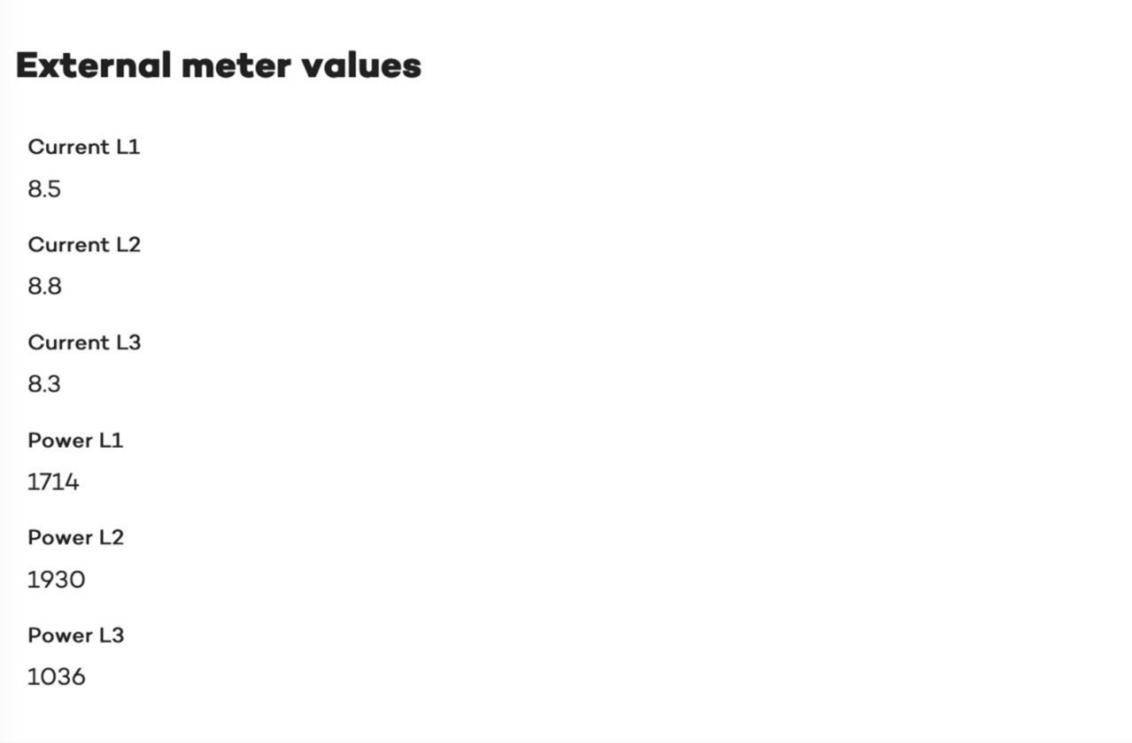


Figure 14. Real-time values from the power meter.

The safe limit log indicates when the safe limit was applied for the group due to loss of real-time values from the measurement device; it is shown in Figure 15.

Safe Limit Log (24 hours)

RELOAD

Timestamp	externalDeviceId	Active	Value
19.04.2021 14:25:26	example-id	false	24.00
19.04.2021 14:24:26	example-id	true	24.00

Figure 15. Safe limit log.

The table with all recent ALM values and calculations is shown in the group overview for debugging purposes. An example can be seen in Figure 16.

DLM 2.0 actions

RELOAD

Timestamp	stationId	externalDeviceId	importLimit	mainCurrent	nonChargersConsumption	freeReserve	powerMeterValues	activeStations
19.04.2021 19:51:56	20522	example-id	125	500	21.98 = totalBuildingConsumption (37.82) - totalChargerConsumption (15.84)	125 = MIN(mainCurrent (500) - nonChargersConsumption (21.98) = 478.02, importLimit (125))	{ "type": "EXTERNAL_METER", "atime": 672173511, "currentL1": 34.68, "currentL2": 31.16, "currentL3": 37.82, "powerL1": 7304, "powerL2": 6240, "powerL3": 7670, "voltageL1": 234.4, "voltageL2": 234.6, "voltageL3": 235.6, "gridFrequency": 50, "ss": 99, "ber": 99 }	[{ "stationId": 20522, "current": 15.84, "charging": 20522, "l1": 0, "l2": 0, "l3": 15.84, "meterValuesReceivedTimestamp": "2021-04-19T16:51:56.919Z" "powerActiveImport": 3709.72, "throttledCurrent": 32, "throttledTimestamp": "2021-04-19T14:23:56.214Z" }]
19.04.2021 19:50:59	20522	example-id	125	500	21.96 = totalBuildingConsumption (37.86) - totalChargerConsumption (15.9)	125 = MIN(mainCurrent (500) - nonChargersConsumption (21.96) = 478.04, importLimit (125))	{ "type": "EXTERNAL_METER", "atime": 672173451, "currentL1": 34.72, "currentL2": 31.3, "currentL3": 37.86, "powerL1": 7298, "powerL2": 6276, "powerL3": 7674, "voltageL1": 233.8, "voltageL2": 234.8, "voltageL3": 235.1, "gridFrequency": 50, "ss": 99, "ber": 99 }	[{ "stationId": 20522, "current": 15.9, "charging": 20522, "l1": 0, "l2": 0, "l3": 15.9, "meterValuesReceivedTimestamp": "2021-04-19T16:50:59.587Z" "powerActiveImport": 3714.17, "throttledCurrent": 32, "throttledTimestamp": "2021-04-19T14:23:56.214Z" }]

Figure 16. Adaptive Load Management values and calculations.

Each row of this table shows one ALM recalculation circle. It makes it possible for the user to see when recalculation happened, ALM settings, calculation of the new current limit, values received from the power meter, and station meter values.

6.3.5 User Interface Implementation

The implementation of additional settings values and graphs in the UI is the same as was described in the Dynamic Load Management chapter of this thesis.

Upon connecting the station to the group, a changeConfiguration request is sent to configure necessary meter values and interval for the charger. Example payload is in Listing 9.

```
{
  "MeterValuesSampledData":
"Energy.Active.Import.Register,Power.Active.Import,Current.Import.L1,Current.I
mport.L2,Current.Import.L3,Voltage.L1-N,Voltage.L2-N,Voltage.L3-N",
  "MeterValueSampleInterval": "60"
}
```

Listing 9. Meter values and interval payload.

Widget with real-time values from the measurement device was done in a separate React component using Hooks. Hooks were introduced in version 16.8, and they allow state utilization and other react features in the functional components without writing a class.

An example of widget implementation is in Listing 10.

```
import React, { useState, useEffect, useCallback } from 'react';

function MeasurementDeviceValues() {
  const { groupId } = props;
  const [values, setValues] = useState({});

  const fetchValues = React.useCallback(async () => {
    try {
      const response = fetchFunction();
      setValues(response);
    } catch (e) {
      showError('Failed to fetch');
    }
  }, [groupId, showError]);

  useEffect(() => {
    fetchValues();

    const interval = setInterval(() => {
      fetchValues();
    }, 5000);

    return function unmount() {
      clearInterval(interval);
    };
  }, [fetchValues]);

  return (
    <div>
      <p>Measurement Device Values: </p>
      {Object.keys(names).map(key => (
          <p>key, value</p>
        ))}
    </div>
  );
}
```

Listing 10. Implementation of widget with real-time values.

In the example above, three React Hooks are used:

- **useState** - creates state to the functional component, returns the current state and a function to update it. It is used to hold and update values from the power meter.
- **useEffect** - invokes side effects that run after the component render cycle. It is used to fetch values after component renders and set intervals to fetch values every 5 seconds afterward.
  Interval is cleared on component unmount. It has a dependency on fetchValues, which is passed as the second argument. It will recreate the effect when only the specified dependency changes.
- **useCallback** - used for optimization purposes since it returns memorized version of the callback that will change only if one of the provided dependencies (groupId, showError) will change.

Values for Safe limit log and Adaptive Load Management table are fetched when component renders and can be fetched again upon clicking on the corresponding button “Reload”. Values are stored in the relation database called Timescale. It is handy for storing time-series data. Fetching data is happening with JavaScript Fetch API.

6.3.6 Logic Implementation

Logic processing of Adaptive Load Management is done by a microservice called “energy-dlm”.

There is only one trigger for ALM recalculation - new meter values from the station. Therefore, recalculation will happen depending on the interval that the station is sending new values. The flow is described in Figure 17.

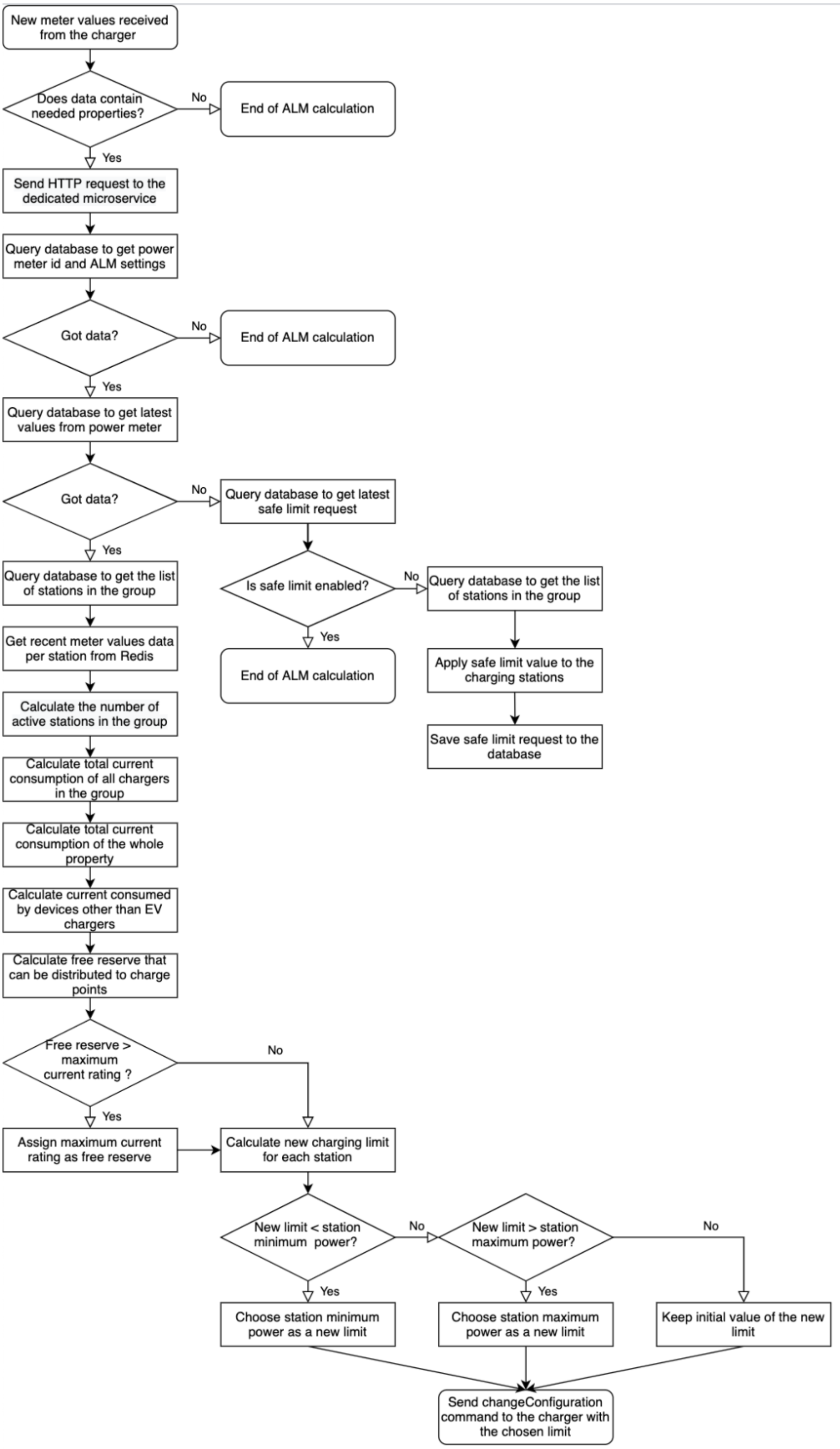


Figure 17. Adaptive Load Management logic flowchart.

The sequence of events:

1 Recalculation happens when new set of station meter values is picked by the microservice in Energy platform from the shared Redis queue. New values are sorted and stored in the separate Redis instance.

2 New meter values are checked to contain needed for ALM calculation properties of current per phase: Current.Import_L1, Current.Import_L2 and Current.Import_L3. If there are no such properties present, the calculation cycle ends.

3 HTTP POST request sent to the “energy-dlm” microservice.

4 Postgres database is queried to check that station is assigned to the group with enabled ALM functionality. Configured settings and the id of a connected power meter are retrieved.

5 Query to the Timescale database is sent to fetch the latest values from the power meter.

6 Query to the Postgres database is sent to get the list of all stations in the group and their maximum and minimum charging power limits.

7 The set of latest meter values reported by the station is taken from Redis storage.

8 The application determines the number of active stations by checking if the station has OCPP status “Charging”.

9 The total electrical current consumption for all active stations is calculated by summarizing values of the most loaded phase of the current.

10 Total building consumption value is taken from either the most loaded phase of current or the one that user defined in the Energy platform UI.

11 The amount of electrical power consumed on the property by other than EV chargers devices is calculated by subtracting total energy used by chargers from total building energy consumption.

12 In order to determine how much of the total power can be allocated to all charging stations application subtracts power consumed by non-chargers from the user-defined grid maximum current rating.

13 The calculated value is compared to the maximum current rating for the group. If the free reserve is bigger, the application will use the maximum current rating value.

14 Chosen value is divided by the number of active charging stations to get the current limit for each charge point.

15 The current limit per charger is compared to the station's maximum and minimum charging powers in the same manner as described in the Dynamic Load management chapter.

16 The chosen current limit is applied to all active stations individually via the changeConfiguration command.

When the Energy platform does not receive updated values from the power meter within 30 seconds, a safe limit is enabled for charging stations. Its value is recalculated every time station sends a new OCPP status message. Logic-wise, a safe limit is acting like a Dynamic Load Management service.

6.3.7 Testing

Adaptive Load Management tests were done systematically and iteratively during the solution development. For all the tests, actual charge points and cars were used. The most recent test scenarios and actual results can be found in Appendix 2.

For the tests presented in this thesis, EV box Gen4 and Alfen charge points were used. As well as three cars: Nissan Leaf, Nissan NV200, and Tesla Model 3. The external load was delivered with a 2 kW heater. The maximum current rating was set to 16 A, grid maximum current rating to 16 A, safe limit to 12 A, and optimization based on the most loaded current phase.

Test scenarios cover various cases:

- External electrical load appears on the site, so total charge points consumption needs to be limited.
- External load drops out, so charging stations can use higher power.
- External meter losing internet connection and Virta backend does not receive real-time values for 30 seconds. It triggers a safe limit to be applied.
- Charge point loses power and shuts down. After the power-up, charging session with previously set ALM limits is resumed by the charging station.
- Station suspends the charging session when receiving the command to charge with zero amperes.

7 Conclusion and Future Improvements

Demand for electric vehicles is constantly rising, and it is safe to predict that they soon will become the primary part of everyday transportation.

Governments across the world promote green mobility and show determination to replace gasoline cars with electric vehicles.

With the increasing number of electric cars, the electricity demand is also growing. Electric vehicles consume a significant amount of electricity. Multiple EVs charging with high power can lead to electrical system overload and a power outage on the site. This problem can be resolved with either costly hardware upgrades or load management on the site. Load management in EV charging efficiently manages electricity consumption, prevents system overload, and saves from high electrical bills.

This project's main focus was to design, implement and test Dynamic and Adaptive Load Management solutions for electric vehicle chargers. The work was commissioned by Liikennevirta Oy Company in Finland.

The project was successful and met customer requirements. Implemented solutions efficiently distribute available electrical power and hold energy demand in line with the available supply. Dynamic Load Management enables equal distribution of available energy capacity among all EV charge points that are charging at the given moment. Adaptive Load Management takes a step further and measures the total amount of electricity consumed at the whole property with further adjustment of power used by the charging stations. Both solutions are implemented in the cloud platform and support multiple charge point models. Constant development and improvement continue for the solutions.

In order to make current load management solutions more versatile, several improvements could be made. When the charge point loses internet connection to the cloud platform, the local controlling unit can become handy to continue energy consumption optimization. Advance phase balancing for multiple charging stations will allow equal distribution of energy consumption among all three phases of current. It will prevent an electrical overload in one phase. Finally, current solutions have limitations in the number of compatible EV chargers they can support. This limitation comes from the necessity to receive specific meter values from chargers. Getting free from these limitations by installing an additional measuring device on the charging site will help to expand the solutions to the currently not supported charger models.

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Appendix 1. Supported charger models

Table 1. List of DLM and ALM supported charger models.

Manufacturer	Model series	Product type / description	Product number	DLM	ALM
Alfen BV	Eve Single Pro-Line	NG910-60003 - Eve Single Pro-Line 1PH T2	904460003	Yes	Yes
		NG910-60005- Eve Single Pro-Line 1PH T2S	904460005	Yes	Yes
		NG910-60007 - Eve Single Pro-Line 1PH Cable	904460007	Yes	Yes
		NG910-60023 - Eve Single Pro-Line 3PH T2	904460023	Yes	Yes
		NG910-60025 - Eve Single Pro-Line 3PH T2S	904460025	Yes	Yes
		NG910-60027 - Eve Single Pro-Line 3PH Cable	904460027	Yes	Yes
	Eve Single Pro-Line DE	NG910-60123 - Eve Single Pro DE 3PH T2	904460123	Yes	Yes
		NG910-60127 - Eve Single Pro DE 3PH Cable	904460127	Yes	Yes
	Eve Double Pro-Line	NG920-61031 - Eve Double Pro-line 1PH1CB	904461031	Yes	Yes
		NG920-61031 - Eve Double Pro-line 1PH2CB	904461032	Yes	Yes

		NG920-61021 - Eve Double Pro-line 3PH1CB	904461021	Yes	Yes
		NG920-61022 - Eve Double Pro-line 3PH2CB	904461022	Yes	Yes
		NG920-61011 - Eve Double Pro-line 1PH1CB	904461001	Yes	Yes
		NG920-61012 - Eve Double Pro-line 1PH2CB	904461002	Yes	Yes
		NG920-61001 - Eve Double Pro-line 3PH1CB	904461011	Yes	Yes
		NG920-61002 - Eve Double Pro-line 3PH2CB	904461012	Yes	Yes
	Eve Double Pro-Line DE	NG920-61101 - Eve Double Pro-line 3PH1C DE	904461101	Yes	Yes
		NG920-61102 - Eve Double Pro-line 3PH2C DE	904461102	Yes	Yes
	Eve Double Pro-Line FR	NG920-61205 - Eve Double Pro-line 3PH1C FR	904461205	Yes	Yes
		NG920-61206 - Eve Double Pro-line 3PH2C FR	904461206	Yes	Yes
Circontrol	Wallbox smart series	RVE-WB2M-SMART-TRI-MID	V23530	Yes	No
		RVE-WBMC-SMART-TRI	V23035	Yes	No
		RVE-WBMC-TOUCH-TRI	V23050	Yes	No
		RVE-WBM-SMART	V23015	Yes	No

		RVE-WBM-SMART-TRI	V23025	Yes	No
		RVE-WBM-TOUCH-TRI	V23045	Yes	No
	eNEXT series	eNEXT Park S	WNA000320x3	Yes	No
		eNEXT PARK T	WNA000320x1	Yes	No
	eVolve series	eVolve S	PVS00064011	Yes	No
		eVolve Smart S	PVS00064011	Yes	No
		eVolve Smart T	PVS00064013	Yes	No
		eVolve Smart TM4	PVS000640B3	Yes	No
		eVolve TM4	PVS000640B3	Yes	No
CTEK	Chargestorm Connected v2	Connect 2 - 2x Type2 socket 3.7 kW	910-17051	Yes	No
		Connect 2 - 2x Type2 socket 11 kW	910-17059	Yes	No
		Connect 2 - 2x Type2 socket 22 kW	910-17060	Yes	No
Ecotap	Homebox	1x AC 22 kW Type2 cable or socket	-	Yes	No
	DUO	2x AC 22 kW Type2 socket	-	Yes	No
	DUO Wide	2x AC 22 kW Type2 socket	-	Yes	No
	DUO Wide Plus	2x AC 22 kW Type2 socket	-	Yes	No
	DUO Wall Charger	2x AC 22 kW Type2 socket	-	Yes	No
Ensto	Chago Wallbox EVB100/200	EVB100-ALB - 1x22kW T2 V2X LAN	EVB100-ALB	Yes	No
		EVB101-ALB - 1x7.4kW T2 RCD V2X	EVB101-ALB	Yes	No

		EVB103-ALB - 1x22kW T2 RCD V2X	EVB103-ALB	Yes	No
		EVB100-BLB - 1x22kW T2 V2X LAN	EVB100-BLB	Yes	No
		EVB100-BLBC - 1x22kW T2 MID LAN	EVB100-BLBC	Yes	No
		EVB103-BLBC - 1x22kW T2 RCD MID	EVB103-BLBC	Yes	No
		EVB100-AWB - 1x22kW T2 V2X WiFi	EVB100-AWB	Yes	No
		EVB101-AWB - 1x22kW T2 RCD WiFi	EVB101-AWB	Yes	No
		EVB103-AWB - 1x22kW T2 RCD WiFi	EVB103-AWB	Yes	No
		EVB200-ALB - 2x22kW T2 V2X LAN	EVB200-ALB	Yes	No
		EVB200-BLB - 2x22kW T2 V2X LAN	EVB200-BLB	Yes	No
		EVB200-BLBS - 2x22kW T2 Shutter	EVB200-BLBS	Yes	No
		EVB203-BLB - 2x22kW T2 RCD LAN	EVB203-BLB	Yes	No
		EVB203E-BLBC - 2x22kW T2 RCD MID	EVB203E-BLBC	Yes	No
		EVB200-A4B - 2x22kW T2 V2X 4G	EVB200-A4B	Yes	No
		EVB200-B4B - 2x22kW T2 V2X 4G	EVB200-B4B	Yes	No
		EVB200-B4BS - 2x22kW T2 S V2X 4G	EVB200-B4BS	Yes	No
		EVB203E-B4BC - 2x22kW T2 RCD 4G	EVB203E-B4BC	Yes	No

		EVF100W-ALB 1x22kW T2 V2X LAN	EVF100W-ALB	Yes	No
		EVF100W-B4B 1x22kW T2 V2X 4G	EVF100W-B4B	Yes	No
		EVF100W-B4BC 1x22kW T2 MID 4G	EVF100W-B4BC	Yes	No
		EVF200W-ALB 2x22kW T2 V2X LAN	EVF200W-ALB	Yes	No
		EVF200W-ALBE2S 2x22kW T2 V2X S	EVF200W-ALBE2S	Yes	No
		EVF200W-BLB 2x22kW T2 V2X LAN	EVF200W-BLB	Yes	No
		EVF200W-BLBC 2x22kW T2 MID LAN	EVF200W-BLBC	Yes	No
	Chago Pro EVF100/200/300	EVF200W-A4B 2x22kW T2 V2X 4G	EVF200W-A4B	Yes	No
		EVF200W-A4BE2S 2x22kW T2 S 4G	EVF200W-A4BE2S	Yes	No
		EVF200W-B4B 2x22kW T2 V2X 4G	EVF200W-B4B	Yes	No
		EVF200W-B4BC 2x22kW T2 MID 4G	EVF200W-B4BC	Yes	No
		EVF200W-B4BCS 2x22kW T2 S 4G	EVF200W-B4BCS	Yes	No
		EVF200W-B4BCD 2x22kW T2 MID 4G	EVF200W-B4BCD	Yes	No
		EVF300W-B4BC 2x22kW T2 MID 4G	EVF300W-B4BC	Yes	No
		EVF300W-B4BCS 2x22kW T2 S 4G	EVF300W-B4BCS	Yes	No
EV-box	Business Line G3	Type 2 AC 22 kW, 1 or 2 sockets w/o Schuko(s)	-	Yes	No

	Business Line G4	Type 2 AC 22 kW, 1 or 2 sockets w/o Schuko(s)	-	Yes	No
Garo AB	GLB Wallbox	GLB-DCM-W-T237FC-A - 1-phase, Type2 fixed cable AC 3.7 kW	353578	Yes	No
		GLB-DCM-W-T274FC-A - 1-phase, Type2 fixed cable AC 7.4 kW	353582	Yes	No
		GLB-DCM-W-T274WO-A - 1-phase, Type2 socket AC 7.4 kW	353579	Yes	No
		GLB-DCM-W-T222FC - 3-phase Type2 fixed cable AC 22 kW	353580	Yes	No
		GLB-DCM-W-T222WO - 3-phase Type2 socket AC 22 kW	353581	Yes	No
		GLB-B-DCM-T222WO-R-LAN - 3-phase Type2 socket AC 22 kW	353457	Yes	No
		GLB-B-DCM-T237FC-A-R-LAN - 1-phase Type2 fixed cable AC 3.7 kW	353453	Yes	No
		GLB-B-DCM-T274WO-A-R-LAN - 1-phase Type2 socket AC 7.4 kW	353454	Yes	No
		GLB-B-DCM-T222WO-R-MC - 3-phase Type2 socket AC 22 kW	353463	Yes	No
		GLB-B-DCM-T274WO-A-R-MC - 1-	353460	Yes	No

		phase Type2 socket AC 7.4 kW			
		GLBDC-T137FC-A - 1-phase Type1 fixed cable AC 3.7 kW	353401	Yes	No
		GLBDC-T174FC - 1-phase Type1 fixed cable AC 7.4 kW	353412	Yes	No
	LS4	LS4M-T222WO	352827	Yes	No
		LS4M-T211WO	352826	Yes	No
		LS4-T222WO	352823	Yes	No
		LS4-T211WO	352822	Yes	No
		LS4M-T211WO V	353059	Yes	No
		LS4-T211WO V	353057	Yes	No
innogy	eBox professional	AC 22 kW Type2 socket	10287478	Yes	No
		AC 22 kW Type2 cable	10287479	Yes	No
	eBox smart	AC 22 kW Type2 cable	10287474	Yes	No
		AC 22 kW Type2 socket	10287507	Yes	No
Tritium	Veefil RT50	Fast charger 50 kW CCS & CHAdeMO	TRI93-50-01	Yes	No

Appendix 2. Tests

Test date: 19.01.2021

Test result: passed

Test setup:

Number & type of cars: 2*1-phase Nissan Leaf, Nissan NV200 & 1*3-phase Tesla 3.

External load: 2 kW external heater added to the site consumption.

Stations: EV box Gen4 (P0134B0125v13.191219): connector id 16029 & connector id 16032, Alfen (8551).

Settings:

Maximum current rating: 16 A

Grid maximum current rating: 16 A

Safe limit: 12 A

Optimization is based on the most loaded phase of current.

Test legend:

DLM related tests have white colour background.

ALM related tests have orange colour background.

Table 1. Dynamic and Adaptive Load Management Tests.

Service	Test scenario	Expected result	Actual result
DLM	Set the DLM parameters so that one charging point can charge with full power. Start charging with one car (1-phase).	The import limit is set to 16 A, meaning that the 11 kW EV box Gen4 can charge with full power at any point. When we start charging with EV box Gen4, the maximum current is 16 A. The charger starts charging with full power.	A Nissan van 200 is connected to the EV box Gen4. Charging is initiated, and the EV box Gen4 starts charging with 16 A.
DLM	Start charging with a second car (1-phase) Nissan Leaf.	Both used charge points share the current (50% each), and together they will not exceed 100% of the grid fuse. 105% transgression (all charge points together) is allowed for 30 seconds.	The import limit of 16 A is evenly divided between these two charging sessions, equalling 8 A per charger.
DLM	Start charging with a third car (3-phase).	The 3 charge points share the current (33.333= 3% each), and together they will not exceed 100% of the grid fuse. 105% PWM transgression (all charge points together) is allowed for 30 seconds.	The import limit of 16 A is evenly divided between these three charging sessions, equalling 5,3 A per charger. The minimum charging power is 6A so this value will be assigned to each charger.
DLM	One of the cars stops charging and leaves.	The PWM of the 2 CPs raises to the max available current of the grid fuse.	Charging is stopped at 13:17. The import limit of 16 A is evenly divided between the two remaining charging sessions, equalling 8 A per charger.

DLM	All three cars are charging again.	The PWM of the3 CPs drops to the max available current of the grid fuse.	Charging is resumed with all chargers at 13:20. The available charging power of 16 A is evenly divided to all three charging sessions, equalling 5,3 A per charger. The minimum charging power is 6A so this value will be assigned to each charger.
ALM	One of the cars stops charging and leaves. Two cars continue charging. The group is subjected to an immediate external load of 8 amps (2 kW heater).	The PWM of all CPs together is reduced to the rest of the possible available current of the grid fuse. The 2 charge points share the rest available current (50% each), and together they will not exceed 100% of the grid fuse. 105% PWM transgression (all charge points together) is allowed for 30 seconds. Maximum current rating: 16 A Grid maximum current rating: 16 A	EV box Gen4 (16029) and EV box Gen4 (16032) are charging 8 A each. After introducing an external load of 8 A, chargers went to 6 A each.
ALM	The external load drops out immediately.	The PWM of the 2 CPs raises to the max available current of the grid fuse.	EV box Gen4 (16029) and EV box Gen4 (16032) are charging 6 A. each. After excluding an external load of 8 A, chargers went to 8 A each.
ALM	Internet connection lost: ALM limit is maintained and installation with external load is protected.	The group safe limit is engaged.	EV box Gen4 (16029) and EV box Gen4 (16032) are charging 8 A each. After the external meter values stop coming for at least 30 seconds, chargers use the safe limit value

			of 12 A, equalling 6 A per charger.
ALM	Internet connection is back: ALM limit is maintained, and the safe limit is disabled.	The group safe limit is disabled.	EV box Gen4 (16029) and EV box Gen4 (16032) are charging 6 A each. After the external meter values come back, the safe limit is disabled, and chargers regain a value of 16 A, equalling 8 A per charger.
ALM	EV box Gen4 charger lost power and was powered on again.	Charger will resume the charging session.	EV box Gen4 (16029) resumed the charging session.
ALM	Send 0A limit.	Charger goes to 'SuspendedEVSE' state.	Charger accepted the 0A limit and entered the 'SuspendedEVSE' state.
ALM	Send 6A limit to the charger that had 0A limit.	Charger resumes charging session.	Charger accepted the 6A limit and entered the 'Charging' state.