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GridShield – Mitigating unforeseen local power peaks on the grid caused by EVs

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Executive Summary

With the increasing adoption rate of electric vehicles, power peaks caused by many cars charging simultaneously in the same low-voltage grid can cause local overloading and power outages. Smart charging solutions should spread this load, but a residual risk of incidental peaks will always remain. A decentralized and autonomous technology called GridShield is therefore being developed to reduce the likelihood of a transformer's fuse blowing in the case of unforeseen or unsuccessfully managed peaks in the grid load. The GridShield functionality acts as a measure of last resort in the energy management system by temporarily limiting the virtual charging capacity of charging stations. It enables optimal use of available grid capacity, while ensuring reliable operation of the grid.

Keywords: Smart charging; energy security; reliability; electric vehicle; electric vehicle supply equipment; infrastructure.

1 Objectives

GridShield is a last resort mechanism for grid stability, designed primarily for use in electric vehicle charging. The objective of our work is to design and evaluate a mechanism that grid operators can use in the near future to reduce the impact of unexpected interruptions in electricity management systems. This will help prevent damage to power infrastructure. The mechanism should reactively mitigate unpredicted events, such as local temporary congestion or Energy Management System (EMS) malfunction, by instructing charging stations to temporarily adjust their electricity demand, but only when other control mechanisms fail to produce a stable local grid situation.

The primary solution to grid congestion is smart charging, which will take time, legislative changes and good incentives to implement [1, 2, 3]. Grid reinforcement as a temporary solution is prohibitively expensive and can take a long time to implement in the Netherlands, due to shortages in both material and knowledgeable personnel.

The main functionality of GridShield is to protect low-voltage grids against unforeseen, temporary overload that could cause a service interruption or premature wear, by ordering a fast change in operation from the charging electric vehicles (EVs). Such interruptions could be caused by either hardware malfunction, failing datacommunication or cyber attacks [4, 5], but situations in which smart charging is working as desired might also result in a temporary overload when the EV penetration in a certain area is very high [6, 7] .As a measure of last resort against local power interruptions, GridShield is designed to be robust, fast, and safe. Being designed by and for grid operators, it will have to take proportionality, privacy, and psychology (human behavior) into account.

By providing feedback to the grid operator on when GridShield is required to intervene, the grid operator receives additional information on the local power grid conditions, which can be used in the planning of grid reinforcements.

The designed solution can play a critical role in the energy transition by ensuring the grid's continued operation while incorporating increasing EV charging demand. Thus, it will help maintain a cost-effective power system. Implementing GridShield is not a guarantee against power outages, but it minimizes the risk of it happening when there are EVs charging.

In this paper, we explore the effects GridShield has in the current and future energy system and estimate its value for EV drivers and the DSO. In order to be able to do so, we developed methods to connect not only with an EMS but also with the standard devices in the low voltage grid. We also developed a feedback system to help identify the periods in which GridShield was activated, in order to analyze the effect it's intervention had on all stakeholders.

2 Materials and techniques

The GridShield system consists of two types of modules per setup: a *sender* module and several *receiver* modules (Fig 1). The sender retrieves measurements at the grid transformer. According to internal control logic and parameters that can be set by the grid operator, it determines if the grid is overloaded or not. If the grid is overloaded, the transmitter will broadcast an over-the-air message with a signal to reduce the maximum power that a charger can draw to a given fraction of the nominal capacity. The receiver module(s) in the neighborhood pick up this message. They will validate whether the message applies to their grid connection and then convert the message into an instruction to the charging station that is connected to the receiver.

GridShield should also not introduce a new risk or point of entry for malicious actors, for instance in the form of cyberattacks.

These modules work without any reliance on external infrastructure, such as wireless networks, internet service, cloud computing or other forms of external processing or mediation. They also contain very little intelligence or analysis. This adds to their robustness, response time, and safety [8].

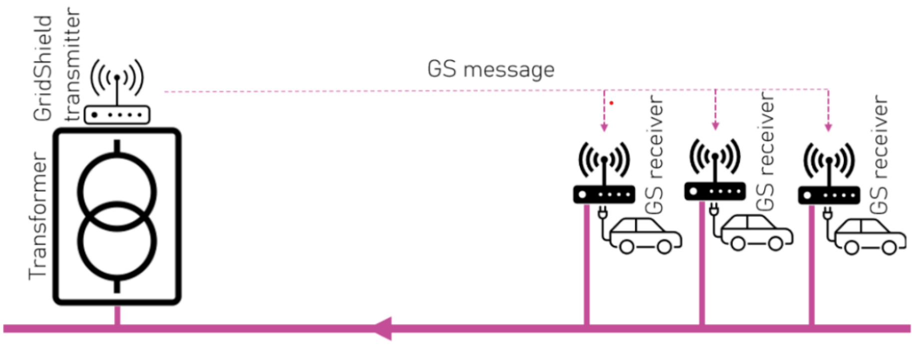

Figure 1: schematic of the order of operations in GridShield.

GridShield is being implemented and researched in three living labs of different scales, contexts and users:

at the University of Twente (UT), Province House Zwolle and at the world's largest bidirectional charging car park at insurance company a.s.r. in Utrecht. All three locations combine solar energy, charging stations, batteries and an energy management system. The users vary from short-stay visitors to full workday parking.

3 Results

Communication protocol

For our previous results [9], we operated GridShield in hardware we had available, which operated using LoRa. Although we succeeded in obtaining the desired communication, future proofing the system is an essential step in the further development and scale up of the functionality. We therefore performed a tech scan on the available frequencies for communication (figure 2).

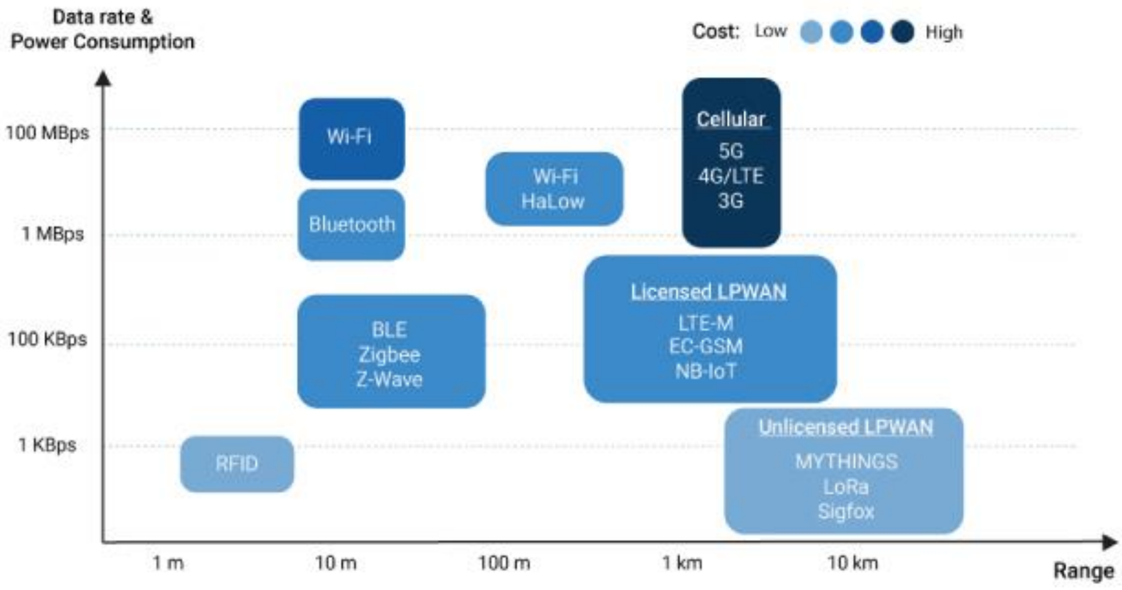

Figure 2: overview of the possible types of communication for GridShield, including LoRa, which was used in the proof of concept.

Since we want to send instructions through a standalone type of communication, the available frequency is an important factor in the design of the hardware. For the Netherlands, these frequencies are listed in table 1.

Table 1: Available frequencies for datacommunication in the Netherlands

Frequency	**Max. channel width**	**Max sending power, at antenna**	**Maximum duty cycle**
169,400 – 169,4750 MHz	<50 kHz	500mW	<1,0%
169,400 – 169,4875 MHz	Geen	10 mW	<0,1%
169,4875-169,5875 MHz	Geen	10 mW	<0,001% between 06:00h and 24:00h, else 0,1%
169,5875-169,8125 MHz	Geen	10 mW	<0,1%
433,050 – 434,790 MHz	Geen	10 mW	<10%

433,050 – 434,790 MHz	For channels using a bandwidth over 250kHz, the power density is limited to -13 dBm/10 kHz	1 mW	None
434,040 – 434,790 MHz	25 kHz	10 mW	None
863,000 – 865,000 MHz	None	25 mW	<0,1%
865,000 – 868,600 MHz	None	25 mW	<1,0%
868,700 – 869,200 MHz	None	25 mW	<0,1%
869,400 – 869,650 MHz	None	500 mW	< 10%
869,400 – 869,650 MHz	None	25 mW	<0,1%
869,700 – 870,000 MHz	None	5 mW	None
869,700 – 870,000 MHz	None	25 mW	<1,0%

The duty cycle allowance translates into allowed transmission periods per day, per machine, as stated in table 2. The presented values are the result of multiplying the amount of seconds per day with the duty cycle.

Table 2: Maximum transmitting time per day per machine

Duty cycle	**Maximum transmitting time per day, per machine**
0,1%	86 seconds
1%	864 seconds
10%	8640 seconds

Lower frequencies need a relatively large antenna and a low bandwidth. Since charging stations are relatively small, using frequencies in the lower ranges causes challenges at the receiving end of the communication. All these factors have been taken into account, as well as additional requirements such as subscription fees and limits on transmitting distance. LoRa in general uses 868.10, 868.30 and 868.50 MHz, with a reach of about 3 km in densely populated areas. The amount of transmitting time available within the frequency is estimated to be sufficient for the desired usage as a safety net for the grid, considering a message is sent and received within seconds [9]. Compared to other technologies (e-sim, PLC and Mesh), LoRa remained the preferred method of communication.

Active control

When in active operation, GridShield senders continuously monitor the load on the involved grid. Depending on the specific measurements that can be retrieved from the grid, trigger values can be entered in the sender module, on which the control will take place. These can be based on whatever parameter is most suited for the location: power, voltage, frequency distortion, etc.

In this project, we are studying all commonly used methods of controlled charging. At the charger level we incorporate direct access to the charger through CanBus/Busbar as well as grouped control through Edgedevice and similar tools. At the transformer level, we can operate GridShield through direct measurements of the transformer as well as through messages of the EMS.

When instructing cars to change their behaviour for GridShield purposes whilst they are operated under an Energy Management System (EMS), it is crucial that the response of the cars is not instantly dissolved by a counterresponse of the other flexible components in the grid, especially in situations in which the overload is local and the EMS control takes place at a higher level. In other words, it has to be ensured that no new EMS commands that increase the load on the system are given whilst GridShield is operational. Would this not be ensured, then the other components would start using the power offered up by the EVs, counteracting the orders of GridShield. In order to avoid such unwanted opportunistic behaviour of the EMS, a logical order of operations is developed to send the GridShield commands through a communications channel in the EV charger that is always "on top" of other commands.Simultaneously, the activation of GridShield is entered as an operator to the EMS algorithms, thus influencing the total behaviour of the EMS. The GridShield signal that is entered as an operator into the EMS needs to be registered, so it can be used for time efficient analysis of the impact of GridShield on the EMS performance.

In tailoring the GridShield command, it is important to get fast results once a GridShield command is sent. The command should not too mellow and not too strict. Especially instructions that are too rigorous will result in low acceptancy of the desired functionality by both the EV driver and the charge point operator, whilst also creating a risk of a rebound-effect. This type of behaviour might even result in damage to the energy system, rather than in protection of it. In our previous work on the effectiveness of steering, we determined the Additive Increase Multiplicative Decrease (AIMD) method to be the most effective control algorithm [8, 9].

The expected respons at cable level is dependent on the relative contribution of flexible (controllable) load on that cable. With a lower flexible load, the initial response per active charging station has to be bigger to obtain the same outcome. We are currently investigating the need for tailor-made response levels, evaluating the response time of the system.

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Presenter Biography

Frank Geerts is chairman of the Dutch working group smart charging as part of the national climate agreement. He is also director smart charging at ElaadNL where he accelerates the widespread market deployment of smart charging. Frank leads a team of experts which is responsible for the coordination of the smart charging program of the Dutch grid operators.

Marisca Zweistra, PhD MSc, studied bioprocess engineering at Wageningen University where she obtained her PhD in 2007. Since then, she has worked in the energy business. First as a general consultant and since 2019 as a specialist program manager on smart charging of electric vehicles.