BATTERY SWAPPING STATIONS

Regulations and safety aspects of battery swapping stations

Rijksdienst voor Ondernemend Nederland

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SUMMARY

The Netherlands is one of the leading countries in the world regarding the number of battery electric vehicles (BEVs) and corresponding charging infrastructure. The ubiquitous charging concept is regular (or fast) charging through a power cable connected to a charging point. An alternative charging concept is battery swapping, where in a swapping station the car battery in need of charging is removed from the vehicle and replaced by an identical battery that has already been fully charged in the installation. Battery swapping technology has already been developed and implemented in a few places in the world in the 2000s but was then seemingly abandoned for strategic and economic reasons. Recently, companies like NIO and CATL have reinvigorated the concept and are rolling it out in China and some areas in Europe, with announced plans to enter the Dutch market as well. Being a new technology in the country, corresponding risks and applicable legislation and regulations may not be entirely clear to the authorities, nor whether further action is recommended or required in this area.

Therefore, the Netherlands Enterprise Agency (*Rijksdienst voor Ondernemend Nederland*, RVO) requested DNV to answer the following research questions with regards to battery swapping stations:

1. What laws and regulations are currently in place in The Netherlands, or being developed, for battery swapping stations and related matters (e.g. swapping and charging batteries there)?
2. What are international developments and experiences with battery swapping stations in other countries (e.g. China and Norway)?
3. How does the technology work in detail? (including charging and discharging, battery storage and transportation, operating conditions, energy supply to the grid, etc.)
4. How safe are battery swapping stations? What safety systems are in place, how are errors/faults monitored, what is the impact of co-located fast charging on safety?
5. Which laws and regulations are applicable? To which extent do they cover all risks? Which gaps exist and how can they be addressed?

These questions are addressed in separate chapters in this report, each of which is summarised in order below.

International experience. In 2007 Better Place (US / Israel) pioneered the technology deploying battery swapping stations for Renault-Nissan passenger EVs. However, commercialisation proved difficult as car manufacturers had no interest in standardizing battery packs and Better Place was declared bankrupt in 2013. By then the company had installed ~55 stations in Denmark and Israel, as well as one pilot station in the Netherlands. Tesla experimented with this technology and built several pilot stations in 2013, but ultimately decided for fast charging instead, citing lack of customer interest.

Battery swapping is making a strong comeback in China in 2022 with car manufacturer NIO and battery manufacturer CATL leading the market, both offering battery swapping station technology and services. The only non-Chinese company currently involved in battery swapping technology is Ample, a US-based battery swapping station manufacturer and service provider. Ample operates five battery swap stations in the San Francisco Bay Area, specifically for Uber drivers. Some other major players in the market include Aulton, BIAC BJEV and Geely.

Technical description. Battery swapping is usually performed in a battery swapping station. Although detailed designs differ, the layout has a common setup:

- *Lane system*: to transfer and/or position the EV to a location ready for handling the battery pack.
- *Handling system / battery swapping system*: responsible for automated transportation, unmounting, swapping and mounting of the battery pack.
- *Storage system (storehouse)*: used to safely store the battery pack and support monitoring of the battery during power transfer between storehouse and battery.
- *Battery charging system*: used to safely charge the battery pack inside the storehouse.
- *Supervisory control and data acquisition (SCADA)*: monitors and controls all battery swap system processes and may have communications with the power grid as well.

The swapping process can be summarised as: parking – identification – authorisation – positioning – battery removal – battery storage – battery replacement – battery mounting – diagnosis – vehicle release.

Safety. All EV and BESS hazards apply to BSSs in principle, fire and thermal runaway being the most prominent. Major hazards specific for battery swapping systems and causes of those hazards are associated to interfaces, as follows:

- *Mechanical hazards*: external/internal battery damage possibly leading to reduced performance or fire and thermal runaway. Potential causes: vehicle misalignment; non-simultaneous electrical / mechanical (dis-)connection; unsuitable physical interface; damaged battery (un-)locking mechanism; battery too heavy for battery transfer unit or vehicle.
- *Electrical hazards*: high current, short circuit, arc flash, shock/electrocution; possibly leading to personal injury, reduced performance or fire and thermal runaway. Potential causes: insulation damage; switch malfunction; connector misalignment, incomplete/incorrect connection; intrusion of water/salt/dust; cooling fluid leakage.
- *Cooling system hazards*: overheating and (coolant) fire possibly leading to thermal runaway. Potential causes: coolant leakage at the connection point between the coolant pipes in the battery and the EV; reduced cooling capacity due to formation of air bubbles in the coolant liquid due to swapping.

Mitigating measures against mechanical, electrical and cooling system hazards are a mostly a part of the design and construction of the battery, the EV and the swap station. Mitigation measures against fire hazards include: BMS monitoring, early warning systems (e.g. temperature / CO / smoke sensors, 24-hour remote video monitoring), fire-retardant separation between battery swapping station and fast charging station, fire suppression system, safety procedures for drivers and operators, emergency response plan.

No additional safety measures are needed for battery swapping stations close to fast charging stations.

Legislation and regulations. Current regulation and legislation are not sufficient to ensure safety of a battery swap station (BSS).

- *Directives*: the Machinery, Low Voltage and EMC Directives are applicable to BSSs and/or their components.
- *CE marking*: this is mandatory, however no harmonized standard applicable to BSSs exists, which gives the designer freedom in interpretation of the applicability of standards. Harmonization of national regulation is strongly recommended, so all stakeholders know what to expect, and which measures/standards are required.
- *Dutch legislation*: the Environmental Management Act and in some cases the Environmental and Planning Act apply to BSSs; a permit is required. The Building Decree contains general regulations for buildings which apply, but no specific regulations for BSSs. Based on the Labour Conditions Act and Labour Conditions Decree, the following standards are applicable: NEN 3140, NEN 3840 and in case the BSS is used as a storage device (e.g. to provide ancillary services) also NEN 4288, although the latter does not specifically address BSSs.
- *Publication Series Dangerous Goods (PGS) 37*: expected to enter into force by early 2023, it is applicable to (large) Li-ion battery energy storage systems and to storage (in a storehouse) of batteries. BSSs are not explicitly included although risks and mitigation are similar.
- *Regulation gaps*: in The Netherlands, no specific regulations are in place for BSSs. Adding BSSs as an additional category (so-called Typical) in PGS 37, plus adding car accessibility requirements, would be an easy way to address BSSs hazards well. Furthermore, a harmonised EU standard on BSSs does not exist and therefore CE marking is not straightforward and should be carefully checked.

Recommendations. Update regulations to specifically include BSSs, e.g. updating PGS-37. Ensure continuous monitoring of the developing technology, with lessons learned fed into updated regulation. Creation of a single point of contact (knowledge desk) for BSSs within the government to support local authorities with requirements and permitting. Supporting the finalisation and publication of IEC 62840-3 (regarding safety and interoperability of battery swap systems) and its harmonisation under an EU Directive.

1 INTRODUCTION

The electrification of vehicles is starting to generate significant traction worldwide. The Netherlands is one of the leading Electric Vehicles (EV) countries with a high rate of uptake of battery electric vehicles (BEVs) and the accompanying EV charging infrastructure, ranking alongside countries such as Norway, Sweden, Germany and China. This is driven by national and local policies such as financial incentives for BEVs and a leading role for municipalities who organise tenders for public chargers.. In 2021 the Netherlands had the highest number of public EV chargers of all countries assessed after China[1].

All of the current charging infrastructure operational in Europe, either public or private, is designed for regular or fast charging of EVs and is based on the concept of a connected power cable between EV and charger. The EV is connected to the charger until the battery is full or the charge session is complete. An alternative method of charging is *battery swapping* whereby an empty battery of an EV is replaced with a fully charged battery. A typical battery swapping process will include a battery swapping station (BSS), where the battery is automatically swapped in a short period of time (e.g. several minutes). Batteries are stored and managed in the BSS and recharged for the next swap. Batteries can be swapped from different directions, depending on the type of EV: passenger EVs from underneath, trucks and buses from the top or side.

The concept of battery swapping is not new, already in 2008 the company Better Place started building and installing battery swapping stations in Israel and Denmark for passenger EVs, and Tesla ran a battery swapping pilot in 2013. However, the concept was abandoned either because of bankruptcy (Better Place) or a different strategy (Tesla).

In the past years China has revamped the technology, with car companies such as NIO and battery manufacturer CATL making a significant push for the technology, based on standardised batteries. NIO is the first company to enter the European market in 2022, with up to a 1300 battery swapping stations already operational in China.[2]

Although the technology has significant drawbacks such as lack of standardization and high station cost, there are a number of advantages to support the current push for battery swapping. Most importantly these are a lower vehicle purchase cost based on a battery-as-a-service (BaaS) model and faster charging times (around 5 minutes compared to 15 to 45 minutes for fast charging).

Even though charging batteries via swapping compared to regular charging mostly relies on the same battery technology, there are some important differences. For example, the battery has to be unmounted and moved to the charging location and vice versa. Within the station itself there are a number of batteries being charged with an energy content similar to regular stationary battery storage systems, potentially providing grid services as well. Due to this difference, current standards and legislation for regular charging or stationary systems might not fully cover battery swapping or battery swapping stations. Because of the known (fire) safety risks of EV batteries it is important to safeguard the battery swapping process.

The goal of this report is to identify safety risks related to installation and operation of battery swapping stations in the Netherlands and to analyze whether there are any gaps in safety regulation to cover these risks. To do so we provide an overview of the international experience in battery swapping technology so far (chapter 2), a technical description of a typical battery swapping station and process, including related safety mechanisms (chapter 4, 5), and insight into current and upcoming legislation relevant for battery swapping stations (chapter 6).

This report focuses on battery swapping technology for passenger EVs, trucks and buses and excludes two- or three-wheelers.

[1] The Netherlands Ranks Fifth in rEV Index 2021 (investinholland.com)

[2] NIO | Nieuws

2 INTERNATIONAL EXPERIENCE

The concept of battery swapping as a charging method for electric vehicles (EVs) has been around since the start of the first commercial adoption of EVs. In 2007 Better Place pioneered the technology deploying pilot battery swapping stations for Renault-Nissan passenger EVs. However, commercialisation proved difficult as car manufacturers had no interest in standardizing battery packs, and Better Place was declared bankrupt in 2013. By then the company had installed ~55 stations in Denmark and Israel, as well as one pilot station in the Netherlands. Tesla experimented with this technology and built several pilot stations in 2013, but ultimately decided for a different strategy based on fast charging, citing a lack of interest from customers.

Battery swapping is making a strong comeback in China in 2022 with car manufacturer NIO and battery manufacturer CATL leading the market, both offering battery swapping station technology and services. The only company outside of China currently involved in battery swapping technology is Ample, a US based battery swapping station manufacturer and service provider. Ample operates five battery swapping stations in the San Francisco Bay Area, specifically for Uber drivers[3].

NIO started their European rollout by opening their first battery swapping station (BSS) in Norway earlier this year (2022). Powerswap is another company based in Sweden who is planning to introduce a different concept of battery swapping. Powerswap plans to swap batteries horizontally from the side and they have demonstrated this concept successfully with Renault Zoe. They aim to provide one such station next to a gas station.

2.1 Battery swapping in China

China has a long track record of battery swapping technology starting as early as 2008 with one of the first pilot projects being the Beijing Olympics showcase of a fleet of 50 electric buses featuring swappable batteries. Another pilot included a taxi project run by Stategrid together with Chinese car manufacturers Zotye and Haima in 2010. Another notable taxi project was setup by BAIC in 2015 including a total of 1.000 EVs and 200 swapping stations.

From 2016 onwards China has seen a range of car manufacturers, battery manufacturers and utility companies enter the battery swapping market. There are currently some 1500 battery swapping stations for passenger EVs in China. These figures include taxis, but exclude specialized stations for trucks, delivery vehicles, buses, and two-wheel vehicles. In 2025, companies plan to have some 20.000 swapping stations in operation in China[4]. The most notable companies which are currently active in the Chinese market are:

- Aulton: Aulton is a service provider which mainly engages in power battery swapping and charging services, battery life cycle management and the commercial operations of battery swapping stations. Aulton received an investment from BP in 2021. Aulton claims it has 630 stations operational with a swapping capability of 50.000 EVs and plans to have 10.000 swapping stations in China by 2025[5].
- BAIC BJEV: One of the first car manufacturers in China to carry out large-scale investment and operation in the EV battery swapping market. At the end of 2020, BAIC BJEV had set up 225 stations in 19 cities in China and had 22.000 battery swapping enabled EVs[6].
- CATL: CATL has announced the launch of a battery-swapping solution Evogo early 2022[7]. This could provide a significant push for the technology, since CATL is the world's biggest battery manufacturer[8]. CATL has helped NIO to develop swappable batteries and has now partnered with Chinese car manufacturers Aiways and FAW Motor to

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3 Ample Is Launching Battery Swapping For EVs, Uber Drivers in the Bay Area First Customers - GreenCitizen
4 https://www.theautopian.com/china-is-already-doing-ev-battery-swapping-and-heres-everything-you-need-to-know-about-it/
5 Oil giant teams up with Aulton to build battery swap stations - Chinadaily.com.cn
6 Besides NIO, who are the other battery swap players in China? - CnEVPost
7 CATL Launches Battery Swap Solution EVOGO Featuring Modular Battery Swapping
8 https://technode.com/2022/02/08/catl-the-biggest-ev-battery-maker-in-the-world-in-2021-with-32-6-of-market-share/

provide compatible EVs for their new Evogo battery swapping service. The Evogo model is based on exchanging a number of smaller battery modules standardized for a range of vehicles, enabling a cost and material efficient approach compared to fixed, large batteries[9].

- Geely: The Chinese car manufacturer Geely has the ambition to set up 5.000 battery swapping stations for EVs in China by 2025. Geely is the first company enabling commercial battery swapping for heavy duty vehicles such as cement trucks.
- NIO: NIO is a Chinese car manufacturer which has produced over 300.000 EVs up to date and is leading the battery swapping rollout. NIO is the only company offering battery swapping for their car models. NIO has plans to offer battery swapping for cars of other brands as well. NIO designs and operates its own battery swapping stations which can exchange a battery within 3 to 5 minutes. NIO plans to have 4.000 battery swapping stations operational worldwide by 2025, including 1.000 outside of China[10]. As of January 2023, NIO have 10 battery swapping stations in operation in Europe – 3 in the Netherlands, 2 in Germany, 3 in Norway and 2 in Sweden. Part of this strategy includes a partnership with Shell for further rollout in both China and Europe[11]. NIO also plans to manufacture part of their battery swapping stations in Europe[12]. NIO's first 200 swap stations implemented were the first-generation design, capable of storing five EV batteries. Swap stations 201 through 1,011 have been the second-generation model, storing 13 batteries alongside a maximum daily service capacity of 312 swaps.

Chinese policy strongly supports the rollout of battery swapping technology in China where it is seen as a key technology required for rapid EV adoption. One of the main reasons for this is the reduced cost to EV drivers as they do not have to purchase the full battery, but instead can lease it based on a battery-as-a-service (Baas) model and choose different sizes depending on their daily driving needs. The Ministry of Industry and Information Technology (MIIT) released the global auto industry's first standards (GB/T 40032-2021) for swapping technology last year, specifying safety requirements, test methods and inspection rules for EVs with swappable batteries. The standard is the first mandatory standard governing the development of battery swapping in the EV industry. The MIIT aims to have more than 100.000 battery swappable EVs and more than 1.000 battery swapping stations by 2023. Stations in the bigger cities will accommodate both passenger and commercial vehicles, while outlying provincial cities will focus on electric heavy-duty trucks.[13]

There are different business models for battery swapping in China. The realization and operation of a battery swapping network can be performed either by a car manufacturer (e.g. NIO); as a joint operation between car manufacturer and station provider (e.g. CATL and Aiways) or by a station provider cooperating with a range of car manufacturers (e.g. Aulton).

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9 CATL launches its EVOGO battery swap services in Hefei

10 https://electrek.co/2022/07/06/nio-power-day-2022/

11 https://www.greencarreports.com/news/1134296_nio-and-shell-partner-for-battery-swapping-and-charging-stations-in-europe-and-china

12 https://www.saurenergy.com/ev-storage/chinese-ev-maker-nio-to-manufacture-battery-swap-stations-in-europe

13 https://www.reuters.com/business/autos-transportation/inside-chinas-electric-drive-swappable-car-batteries-2022-03-24/

3 TECHNICAL DESCRIPTION

A battery swapping process can be manual, semi-automatic or fully automatic. A manual battery swapping systems can be considered as EV service, that is not accessible for the public and not intended for daily use. This report focusses on the automatic battery swapping system.

3.1 Battery swapping station layout

Battery swapping is usually performed in a battery swapping station. Although detailed designs differ, the layout has a common setup. The following description is based on IEC 62840 “Electric vehicle battery swapping system” and the NIO and CATL Evogo battery swapping stations.

A battery swapping station (BSS) can swap batteries of EVs when the vehicle powertrain is turned off. The BSS operates fully automatically and typically consists of the following parts (Figure 3-1):

- Lane system:
  The lane system is used to transfer and/or position the EV to the designated location to get ready for handling battery pack. EVs leave safely through the lane system after the battery swap is complete. The lane system may provide functions such as EV verification, positioning, locking and unlocking.
- Handling system/ battery swapping system:
  The battery handling system is generally composed of several mechanical, electromechanical, and electric subassemblies that provide automated transportation, mounting, unmounting, and swapping of the battery pack. It consists of a swap and transferring equipment. The handling system shall ensure that the removable battery system is correctly placed and latched or unlatched, if applicable, at each phase of the transport or movement including placement in the EV or in the storage system.
- Storage system:
  The storage system (the storehouse) is used to safely store the battery pack and support monitoring of the battery during power transfer between storehouse and battery and during storage without power transfer. The system consists of a storage rack with storage compartments for each battery.
- Battery charging system.
  The battery charging system is used to safely charge the battery pack. It moves the battery pack to the charging rack and controls the charging and its safe operation by communicating with the battery control unit (BCU) during the charging procedure. Each battery compartment which provides power transfer between BSS and battery pack has a connector for charging, battery management system (BMS), sensors and a thermal management system.
- Supervisory control and data acquisition (SCADA).
  The supervisory and control system monitors and controls all battery swapping system processes and may have communications with the power grid as well. It consists of communication units, data processing and storage module, data acquisition units, a remote-control module and human machine interface (HMI).

Other parts to be considered are the logistic system between BSS and external facilities, operation and maintenance system and bidirectional power supply between BSS and the power grid.

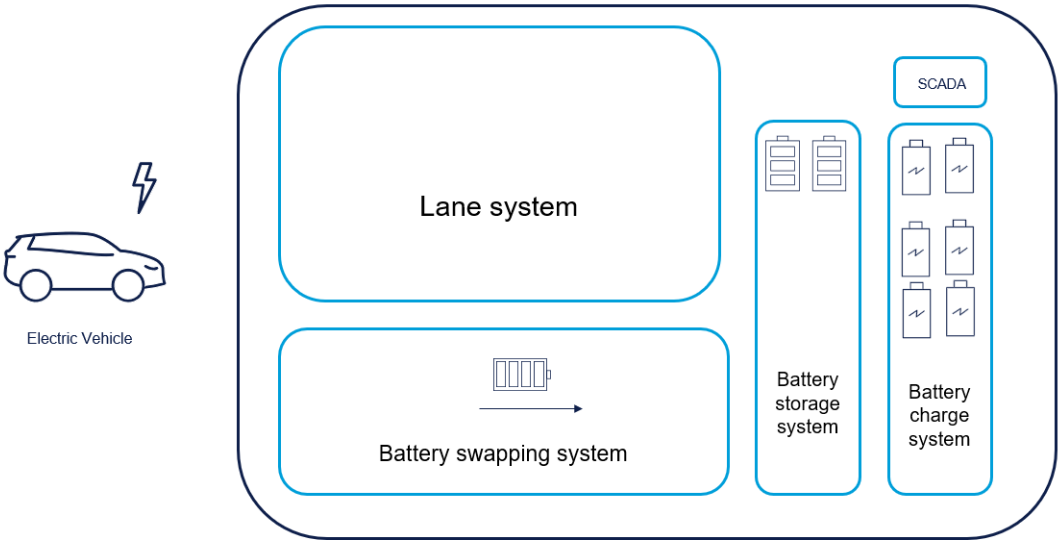

Figure 3-1 Battery swapping system architecture

3.2 Examples of battery swapping stations

The typical battery swapping station has a storage capacity of 10 – 15 batteries with 75 – 100 kWh capacity each. Figure 3.2 shows an artist impression of the NIO and CATL Evogo BSS, both with a similar architecture.

Figure 3-2 Artist impression of the NIO (left) and CATL Evogo (right) battery swapping stations.
Source: https://www.nio.com/nio-power **and** https://www.catl.com/en/news/856.html.

NIO : NIO does not distinguish between the storage and charging part, and refers to both as the “Battery hotel”. Currently the maximum energy capacity stored in the battery hotel of NIO is 1300 kWh, in the starting phase of operation not all available capacity is used.

CATL Evogo: CATL Evogo stores the batteries in blocks and each block consists of batteries with 26.5 kWh of total energy capacity (CATL Choco SEBs). Each station has wireless BMS, 3 parking spaces and 48 Choco SEBs. The Stations are adjusted according to weather conditions.

3.3 Operational process

The operational process of a BSS consists of much more than just the battery swapping process. The continuous operation of a BSS includes:

- Battery swapping process
- Charging the batteries using an energy management system
- Storing and monitoring of the batteries
- Power grid services (optional).

3.3.1 Battery swapping process

The general battery swapping process consists of the following steps:

1. Parking – Driver parks his EV in the vehicle lane zone, this can be outside or inside the BSS
2. Identification – BSS identifies the EV type and model as authorized for battery swapping
3. Authorization – Driver authorizes the battery swapping session by e.g. phone app
4. Positioning – BSS and EV align for unmounting of the battery
5. Battery removal – Empty battery is unmounted by the handling system
6. Battery storage – Empty battery is placed into the storage system by the handling system
7. Battery replacement – A full battery will be taken out of the storage system by handling system
8. Battery mounting – The handling system mounts the full battery onto the EV
9. Diagnosis – EV power up and system check
10. Vehicle release – Driver exits BSS over lane system.

Battery decoupling is performed by the handling system. Battery coupling interfaces are:

- Mechanical alignment and fixation locks
- DC main battery power
- Low-voltage connection for BMS supply (can be from DC battery)
- Monitoring & Control signals (can be wireless)
- Liquid cooling connectors between EV and batteries (Air cooling is also used but not common in modern EVs).

3.3.2 Charging of the battery

Charging the battery pack requires a voltage converter and a DC coupler on the side of the BSS, as well as a DC coupler and optional DC/DC converter at the side of the battery system.

A BSS should have a DC coupler and voltage converter for each battery system. This allows for completely independent power transfer and isolation of the battery systems. Standardization for such components is currently under development by IEC (IEC 61851-3: Electric Vehicles conductive power supply systems).

3.3.3 Battery storage and monitoring (when not in use)

The battery packs while not in use are stored in the battery storage area with each battery pack connected to an Energy Management System (EMS) to monitor the charging process, SOH and SOC of each battery, temperature monitoring, cooling system. The battery packs while being stored can be used for providing grid services: peak shaving, FCR etc. For example, battery swapping stations by NIO will have the technology to supply energy back to the local grid during peak hours (i.e. bidirectional charging or vehicle-to-grid – V2G)[14].

3.3.4 Transport between BSS and external facility

A central location to receive default batteries and to supply new batteries to battery swapping stations is a requirement for efficient operation of swap stations. The responsibility to transport the batteries back and forth is often outsourced to local transport companies provided that they comply with transport regulation for batteries e.g., UN 38.3,ADR[15].

3.4 Operating conditions

The main operating conditions of the battery swap station are:

- **Storage conditions:** Each storage compartment shall be provided with a temperature sensor to monitor the temperature. The power transfer to the batteries shall be stopped if the temperature of the room is above a specific temperature, for example 60 °C[16], and an alarm shall be initiated.
- **Zones:** The battery swapping system shall be divided into 3 separate zones: Vehicle Lane zone, Battery swapping zone, Battery storage and charging zone. The accessibility to these zones shall be controlled according to the safety levels needed.
- **IP rating:** If the swapping system is used indoors: If the battery system connector is not connected: IP21 and if battery system connector is connected: IP44. For outdoor use: battery system connector not connected: IP24 and battery system connector connected: IP44.

In addition to the above, there shall be overload and short circuit protection, emergency disconnect switch, hazard marking, operation instructions provided with battery swapping stations.

[14] NIO testing swap stations that can send energy back to the grid (electrek.co)

[15] ADR comprises **regulations for road transport with regard to packaging, load securing, classification and labelling of dangerous goods**

[16] IEC PAS 62840-3:2021 © IEC 2021

4 SAFETY

DNV has been involved in several root cause analyses for battery fire incidents and from this experience can mention that the risk of lithium-ion batteries catching fire during charging is an issue that has emerged as a critical one[17]. When it comes to battery swapping, a mistake in the swapping and/or charging process could lead to battery damage or even battery fire, which has a high impact. Because the battery needs to be swapped multiple times during the life of the EV, the connection between the battery and the EV must be reliable and safe. Also, the swapping station itself must be designed in a safe manner. Each swapping station contains multiple battery packs which are charged at different currents depending on the charge status of each battery, which adds to the risk. For the location selection of swapping stations, it is recommended to follow PGS 37-1 guideline and the swap stations should prove that the risk of explosion is mitigated.

4.1 General safety risks for EVs and grid-connected batteries

Safety hazards of EVs and grid-connected batteries also need to be considered for BSS. The main hazards related to EVs are: mechanical damage to the battery due to the shocks and vibrations while driving the EV (including collisions); electrical hazards inside the electrical system and battery of the EV; hazards due to leaking cooling fluid (that can be electrically conductive and flammable); thermal hazards due to high temperatures in the Summer and cold temperatures in the Winter time; overheating and fire due to internal battery failure; and external fire. The main hazards related to grid-connected batteries, like BESS, are the same electrical, thermal, cooling fluid, battery failure and fire hazards as mentioned for EV. The main mitigating measures to prevent the hazards and contain or mitigate their effects are: safe design; robust enclosure to protect and seal the battery; BMS to control the EV and battery/BESS operation; thermal management system; continuous monitoring of the systems; emergency shutdown and alarm system; fire alarm and suppression system.

4.2 Specific safety risks for battery swapping

In addition to the hazards mentioned in the previous section, the main safety risks of a BSS are at the interfaces between the EV, the battery and the swapping station. Furthermore, the fire risk due to thermal runaway in Li-ion batteries is addressed with focus on the special situation of the BSS, i.e. a confined space with people present.

The EV and the battery have four interfaces between them. The swap/recharge station and the battery have the same interfaces:

- Mechanical interface
- Electrical interface
- Cooling system interface
- Data interface

The following subparagraphs describe the first three interfaces and their associated risks. The data interface has no associated significant safety risks (although cyber security should be considered). In addition, fire safety is an important consideration for Li-ion batteries in any circumstance, which is described in the last subparagraph.

4.2.1 Mechanical safety

The mechanical interface is the place where the battery unlocking/locking is done (both on/off the EV and on/off the recharge rack inside the BSS). The mechanical hazards associated with the battery unlocking/locking mechanism are external or internal damage to the battery pack and/or the cells inside. Causes of these hazards may be misalignment

[17] Fire at 20MW UK battery storage plant in Liverpool - Energy Storage News (energy-storage.news), Investigation confirms cause of fire at Tesla's Victorian Big Battery in Australia - Energy Storage News (energy-storage.news), Electric bus battery explosion fires - Grid Edge, Electric Buses on Fire after Huge Explosion at London Transport Depot - YouTube

between battery and dock, wear and tear of the connectors, dropping the battery during the swapping process. The impact on battery performance could be reduced power or capacity and reduced cooling capability. The worst effects would be cell degradation due to damage, dust or moisture, and external or internal short circuit leading to thermal runaway.

Mitigating measures to be considered are: robust battery pack design; modules and cells inside pack must be sealed against intrusions; proper interface alignment during swap; the mechanical interface must be anti-corrosive, water/dust/gravel resistant, reliable/durable, and operationally safe; the battery transferring unit must have the required capacity to withhold the weight of the battery; battery shut-down by BMS in case of failure.

Safety risks: the risk of thermal runaway due to mechanical hazards is negligable, assuming that the EV battery has the protection measures that are normal in EVs (i.e. the cells are sealed, the module cover is protecting the cells and the pack cover is protecting the modules). Intrusion of dust, water or gravel into the pack could reduce performance, but will not be a safety risk.

As a general mitigating measure, the connecting/disconnecting bolts should be suitable for regular swapping operation and should be monitored/checked regularly. The interface offered by different suppliers/companies should be compliant to the applicable standards (a list of applicable standards is provided in Appendix B). DNV could not verify against which standards the current swap systems in the market are certified.

4.2.2 Electrical safety

The electrical interface assures the connection at the electrical energy transfer point (high-voltage circuit) and the battery control system's power supply (low-voltage circuit). The main risk points at the electrical interface are mentioned here.

The main electrical hazards are: high current; short circuit; arc flash; and electric shock to a person (in extreme case: electrocution). The causes of these can be insulation damage due to wear and tear of connectors; switch malfunction; connector misalignment; incomplete/incorrect connection; intrusion of water, salt, dust; cooling fluid leakage.

The worst effects that can happen are: personal injury; system damage and overheating; cell damage leading to high current, overheating, fire and/or thermal runaway.

Mitigating measures are: proper electrical insulation; covering live conductors; continuous monitoring and control of temperature, voltage and current; switch off when temperature, voltage or current is too high; controlled switches (and fuses, disconnectors) and protection systems; BMS/EMS; emergency shutdown (auto and manual); temperature monitoring in the swap station; fire detection, alarm and suppression systems.

The risks of short circuit and electric shock are elevated for a BSS because of the semi-permanent nature of the battery interface connections and the repeated disconnection and reconnection actions. Therefore, it is important to have robust and safe electrical connectors. The other mitigating measures are similar as in EVs and BESS.

The electrical safety features of a battery swapping station should comply with the EU regulations and standards, such as IEC 60364 for electrical safety, IEC 60204-1 for general safety of machinery, ISO13849-1 for safety of control equipment and other standards (e.g. for the connectors) as applicable (see Appendix B). Compliance of electrical equipment to these standards shall be verified. DNV could not verify against which standards the current systems in the market are certified.

4.2.3 Cooling system safety

The Li-ion battery produces heat during its operation (both in the vehicle and in the BSS). Therefore, a cooling system is necessary to maintain the temperature of the battery at optimal levels, and thereby optimise the battery life and ensure its safety (since extreme overheating can cause thermal runaway). Liquid cooling is the most popular technology used in EVs to effectively cool the cells inside the battery (air cooling is often used in stationary BESS). A liquid coolant/refrigerant, e.g. ethylene glycol, is used to cool the battery. Many efficient coolants are also electrically conductive and/or flammable, which can cause hazards when the fluid is leaking from the cooling system. The effects of the leakage could be a short circuit in the electrical system or inside the battery; or a fire caused by the flammable fluid falling on a hot surface. Both could eventually lead to cell overheating and thermal runaway.

In a BSS, this leakage could happen during the swapping process, while also the cooling circuit is disconnected or reconnected. Therefore, the cooling leakage probability of occurrence is expected to be higher in a BSS than in an EV or a BESS.

Therefore, the main mitigating measure for the cooling system in an EV with a swappable battery and in a BSS is to have high-quality connectors. The battery swapping companies shall ensure use of high-duty couplers/connectors between the cooling system (of the EV or the BSS) and the battery to support the number of battery swaps promised by the company and prevent leakage of cooling liquid. DNV did not investigate evidence of the usage of such a high-duty coupler in battery swapping systems currently in the market.

4.2.4 Fire safety

Batteries can go into thermal runaway, a self-sustaining process in which heat, fire and oxygen are produced. Not only can (toxic) gases and heat impact the battery system itself, but also its surroundings. Furthermore, some of the gases produced are flammable and explosive, which could lead to an explosion inside the BSS.

It is not possible to stop a thermal runaway once it is started, but several levels of safety in the battery swapping station can prevent thermal runaway or mitigate its impact.

- BMS monitoring: it is required that all battery packs are always monitored, also in storage and during charging. In case deviating or dangerous values are observed, the system can take automatic action intended to prevent thermal runaway and warn operators.
- Early warning systems (sensors and detection): various sensors can detect early stages of a thermal runaway, e.g. off-gas sensors, smoke detection, CO detection, hydrogen detection and temperature sensors. A detection system is mandatory to detect issues in an early stage. 24-hour remote video monitoring (CCTV) should support a proper assessment of the status of an incident.
- Fire isolation: In the battery swapping room persons can be present. It is therefore recommended to separate the battery storage and charging station from the swapping room with a fire-retardant wall.
- Fire suppression system (FSS): Since a BSS will often be placed close to buildings/houses, it is mandatory to implement a fire suppression system. Although an FSS cannot stop a thermal runaway, it can ensure that external fires will not start a battery fire. Also, most FSS effectively cool the system on fire, so the fire propagation is limited and contained.
- The fire suppression should be combined with means to prevent build-up of explosive gases (e.g. ventilation) and to mitigate damage in case of explosion, e.g. by overpressure vents or deflagration (blow-out) panels.
- Emergency response considerations: A person can be present in the car during the swapping process. It is therefore important that:
    - the car driver and BSS operator can always trigger an emergency stop, e.g. through a dedicated button or initiated in a reliable other way such as by opening the car doors
    - the car doors can always be opened from the outside as well as from the inside
    - the driver and any passengers are always able to step in and out of the car while swapping is in progress, without any safety issues (i.e. mechanically and electrically shielded from the process, and ample space

around the EV to move around). If this is not possible, then no passengers should be inside the car during the process.

An emergency response service might need to remove the driver and any passengers from the car. The emergency service, therefore, needs to have a good understanding of the system and needs to be instructed on which actions are safe to take. Therefore, both an emergency response plan and instructions to the fire brigade are strongly recommended. Furthermore, accessibility of the EV inside the swap room and the batteries inside the recharging room is an important safety feature for the emergency responders to act effectively.

4.3 Safety certifications

Each product/device on the market in the European Union needs a Conformité Européenne (CE) marking to be sold and operated in all EU member states. In a CE statement the producer claims that the product, service, or process meets defined criteria and defined safety-relevant aspects. Because there are no harmonized standards for BSSs, it is important that such a CE certificate lists the standards that were checked/reviewed, since there is presently no common consensus about which standards should be included to show CE conformity. The CE declaration should cover aspects like electromagnetic compatibility[18], electrical safety and battery safety.

4.4 Fast charging stations

Battery swapping station providers have plans to provide their customers with the option to operate fast charging stations next to battery swapping stations. This gives the EV drivers the option to choose between fast charging or battery swapping service. Both facilities share the same grid connection. The fast-charging stations and battery swapping stations communicate with each other about the power demand on either side to ensure safe operation of the electric power system. DNV has the opinion that no additional safety measures are needed to ensure safe operation of the fast-charging stations and BSS together (apart from the safety requirements for all individual systems). However, cyber security measures need to be taken for BSS and fast charging stations.

[18] https://www.nio.com/news/nio-power-swap-and-charging-equipment-acquired-ce-tuv-certifications-and-departed-norway

5 LEGISLATION

A battery swapping system should comply with European and national legislation. This chapter lists the legislation and regulation that is applicable to battery swapping stations. Regulation should assign standards that can be used to show the safety of a system. Therefore, this chapter starts with a section (5.1) about the suitability of IEC standards. Then, the relevant directives of the European legislation are listed (section 5.2). Section 5.3 describes the Dutch legislation and the regulation that is in development. In section 5.4 a comparison is made with the Norwegian and German legislation.

5.1 IEC standards for battery swapping

There are three relevant IEC standards for battery swapping: IEC62840-1, IEC62840-2, IEC62840–3. IEC62840-1 presents the technical specification requirements for Battery swapping Systems (BSS), describes each component of the BSS and their function. IEC62840–2 outlines the safety requirements for the BSS and its components. IEC62840 3 is a pre–standard published in September 2021 and is valid only for two years. This standard also focuses on safety and interoperability requirements for BSS. The major difference between IEC62840–2 and IEC62840–3 is that the references to other IEC standards that further elaborate the safety requirements for individual components are rather limited in IEC62840–2, since this standard was prepared in 2016. IEC62840–3, on the other hand, refers to relevant IEC standards to describe the safety requirements for individual components/functions. The standard also presents the test procedures for the required components. IEC62840–3 can be considered as much more elaborate with respect to the safety requirements for BSS. The disadvantage is that the standard is valid for only 1 more year. As the industry is moving forward, this creates an immediate requirement for an IEC standard that focuses on describing the latest safety requirements for BSS with references to IEC standards applicable to individual components.

5.2 Europe

The most important legislative measures in the EU are regulations, directives and decisions. Regulations are binding and directly applicable throughout the EU. An EU Directive is a legislative act that sets out a goal that all member EU countries must achieve. The respective countries can individually define their own laws on how to abide by the respective EU Directive. Decisions are specific measures that are only binding on the EU country or company to which they are addressed. The challenging part is to define what regulations and directives are applicable. The directives that are applicable to battery swapping stations are the Machinery Directive (Section 5.2.1), Low Voltage Directive (Section 5.2.2), EMC Directive (Section 5.2.3) and the Batteries Directive (5.2.4). With a CE declaration a company declares to follow the directives. The CE declaration procedure is described in Section 5.2.5.

5.2.1 Machinery directive (MD)

The EU machinery directive 2006/42/EC[19] refers to the legislation governing the harmonisation of essential health and safety requirements for machinery. Machinery is an installation containing moving parts. Therefore, the MD is applicable to BSS. The Machinery Directive provides guidance for performing a risk assessment (for health and safety) and possible means (by control systems) to mitigate risks (i.e. prevent harm) and guidance for the application of safety components, such as BMS and EMS (with safety functions). A BSS is not listed under one of the 23 product categories. This means that there are no harmonised standards assigned, and there is no involvement needed of an (independent) Notified Body to show compliance. There is freedom in interpretation of sufficient safety measures.

5.2.2 Low voltage directive

The Low Voltage Directive (LVD) 2014/35/EU[20] refers to the legislation that ensures that electrical equipment and components below 1 kV AC and below 1.5 kV DC provide a high level of protection within the EU health and safety

[19] European Commission, "Directive 2006/42/EC on Machinery" [Online]. Available: EUR-Lex - 02006L0042-20091215 - EN - EUR-Lex (europa.eu)
[20] European Commission, "Directive 2014/35/EU on Low Voltage" [Online]. Available: EUR-Lex - 32014L0035 - EN - EUR-Lex (europa.eu)

requirements. The LVD covers electrical safety requirements for the system level and for all electrical components of the BSS. The main hazards covered by the LVD are electric shock and short circuit.

The BSS is electrical equipment, and when placing electrical equipment on the EU market, the manufacturer has the responsibility to ensure and to declare that the products conform to the applicable legislative requirements. Directive 2014/35/EU does not require notified bodies to carry out the conformity assessment procedure. Since no harmonized standard of a BSS exists to show LVD compliance, there is some freedom of interpretation.

5.2.3 EMC directive

Electromagnetic compatibility (EMC) describes the ability of electronic and electrical systems or components to function correctly when they are in close proximity to each other, by limiting their mutual electromagnetic disturbances (i.e. emission levels). It is also vital that each component has sufficient level of immunity to the disturbances in its working environment.

The EMC Directive 2014/30/EU ensures that electrical and electronic equipment used in EU does not generate or is not affected by electromagnetic disturbance. The EMC Directive is hence a legislation governing the immunity of equipment to interference and the electromagnetic emission threshold of these equipment[21]. The directive lists 158 standards, of which none specifically applicable to a BSS. The EMC tests should be performed by a Notified Body, which is an independent institute accredited to perform the tests.

5.2.4 Batteries Regulation

The European Commission proposed a new Batteries Regulation on 10 December 2020. This Regulation aims to ensure that batteries placed in the EU market are sustainable and safe throughout their entire life cycle. Green deal aims to ensure sustainable batteries for a circular and climate neutral economy. Batteries placed on the EU market should become sustainable, high-performing and safe all along their entire life cycle. Green deal promotes the use of responsibly sourced materials with restricted use of hazardous substances, use of minimum content of recycled materials, ensure carbon footprint performance (> 2 kWh) and durability (removability, replaceability) and labelling meeting collection and recycling targets. The Batteries Regulation is expected to come into effect in the second half of 2023, the standards to which it will refer will take approximately another two years to be published. It is not yet clear to which extend the Batteries Regulation will be applicable to BSS.

5.2.5 CE declaration

Each manufacturer in Europe has the responsibility to develop a safe product. CE marking indicates that a product has been assessed by the manufacturer and deemed to meet EU safety, health and environmental protection requirements. It is required for products manufactured anywhere in the world that are then marketed in the EU. CE declaration is meant for consumer products, not mandatory for fixed installations like BSS. Nevertheless, following the CE procedures is a good guideline to design a safe installation.

The most straightforward approach is to comply with a Directive is to use the harmonised standards[22] linked to it. Compliance with harmonised standards provides a “presumption of conformity” with the corresponding requirements of harmonisation legislation/Directives. Manufacturers, other economic operators or conformity assessment bodies can use harmonised standards to demonstrate that products, services or processes comply with relevant EU legislation. If no harmonised standards are applicable to your product, other European standards, IEC or ISO standards, or other international standards may be used to demonstrate compliance to the Directive. Product groups that are applicable to the BSS are mentioned in the next sections. The list of standards applicable to BSS can be found in Appendix B.

[21] European Commission, “Electromagnetic Compatibility (EMC) - Directive 2014/30/EU,” [Online]. Available: https://ec.europa.eu/growth/single-market/european-standards/harmonised-standards/electromagnetic-compatibility_en

[22] EU website harmonized standards, http://ec.europa.eu/growth/single-market/european-standards/harmonised-standards_en

5.3 Dutch legislation

The Dutch legislation consists of two pillars:

- Product safety is covered in the permitting process by environmental act (5.3.1.1) and building decree (5.3.1.2)
- Operational safety is covered by Labour Conditions Act (*Arbowet*) & Labour Conditions Decree (*ARBO-besluit*)

5.3.1 Environmental and Planning Act (*Wet algemene bepaling en omgevingsrecht*[23])

The Environmental and Planning Act (Wet algemene bepalingen omgevingsrecht WABO) governs the integrated planning process in the Netherlands. BESS projects require two specific parts of the environmental permit, the environmental section and the construction section:

5.3.1.1 Environmental Management Act (*Wet milieubeheer*[24])

The general rules of the Environmental Management Act and in certain cases a permit requirement under the Environmental and Planning Act (Wabo Environment Permit) apply to establishments (Dutch: *inrichtingen*). A particular activity can be defined as an establishment under the Environmental Management Act when the activity encompasses economic activity within a delimited area ánd a category from Annex I to the (Besluit omgevingsrecht[25]) applies. The storage of lithium-ion batteries falls into this Category 4.1(a), which include devices for the manufacturing, processing, processing, storage or skipping of dangerous substances category.

Considering the size and activity of the BSS, it is considered being an establishment and therefore an environmental component of the permit is required.

5.3.1.2 Building Decree (*Bouwbesluit*[26]):

A BSS needs to conform with the Building Decree 2012 (Dutch: *Bouwbesluit* 2012). The construction component is required for the (partial) construction of buildings or structures to assure (fire) safety, load bearing, stability etcetera.

The Building Decree contains regulations on the (re)building and demolition of buildings, open yards and land and on safety during construction and demolition. The Building Decree contain regulations to guarantee the minimum necessary quality of construction, distinguishing between new construction, existing construction and conversion by level of requirements. The Building Decree did not take into account the presence and use of lithium-ion energy carriers in a structure, open yard or site. The Building Act therefore does not contain any specific rules for BSS.

5.3.2 Labour Conditions Act (*Arbowet*) & Labour Conditions Decree (*ARBO-besluit*)

The Dutch *ARBO-wet*[27] (Labour Conditions Act) and *ARBO-besluit*[28], Labour Conditions Decree, apply to working on and in the vicinity of an electrical installation. NEN-EN 50110 has been designated as the current European safety standard as mentioned in the Working Conditions Decree. The requirements of EN 50110 are further elaborated for the Netherlands in the current standards:

- For low voltage: NEN 3140 + A1 Operational management of electrical installations – Low voltage
- For high voltage: NEN 3840 + A1 Operational management of electrical installations – High voltage.

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[23] Wet algemene bepalingen omgevingsrecht, https://wetten.overheid.nl/BWBR0024779/2018-07-28
[24] Wet milieubeheer, https://wetten.overheid.nl/BWBR0003245/2020-07-01
[25] Besluit omgevingsrecht, https://wetten.overheid.nl/BWBR0027464/2020-01-01/#BijlageI
[26] Bouwbesluit 2012, https://wetten.overheid.nl/BWBR0030461/2020-07-01
[27] Arbeidsomstandighedenwet, https://wetten.overheid.nl/BWBR0010346/2020-01-01
[28] Arbeidsomstandighedenbesluit, https://wetten.overheid.nl/BWBR0008498/2020-07-01

The NEN 4288 "Operational management of BESS" [29] describes additional requirements to the NEN 3140 and is applicable to systems with a total energy capacity of more than 25 kWh. A battery swap station that will also provide ancillary services would fall under the definition of the NEN 4288 which defines BESS as "designed for the storage of electrical energy" and "can be temporary or permanent, stationary or mobile". The NEN 4288 contains:

- General guidelines for risk analysis
- Control and organization: inspection procedures, maintenance, responsibilities, automation and cyber security
- Characteristics: information availability for stakeholders to inform about the system
- Safety information and documentation.

The NEN 4288 is written for grid-connected battery energy storage systems, it is recommended to add an appendix specifically for battery swapping stations.

5.3.3 Publication Series Dangerous Goods, nr. 37

In July 2020, the Dutch government gazette published a Circular[30] on 'risk control of Li-ion energy carriers'. This Circular contains advises to increase the safety in the environment of lithium-ion energy carriers. It does not contain binding requirements, but is an advice to the competent authority. The Circular is applicable to all lithium-ion energy carriers, and therefore also to the BSS. Appendix C summarizes the requirements from the Circular.

The Circular will be replaced in Q4 2022/ Q1 2023 by the Publication Series Dangerous Goods 37 (*Publicatiereeks Gevaarlijke Stoffen Lithium-ion accu's: opslag en buurtbatterijen*[31]) on lithium-ion battery systems, which is currently in development. The PGS consists of two parts: 37-1 Battery energy storage systems and 37-2 Warehousing of lithium-ion batteries. The BSS does not fall into either one of the categories, although parts of both are relevant for BSS:

- PGS 37-1 applies to rechargeable energy carriers containing lithium that are electrically connected (in groups) to each other with a total installed capacity in a room of more than 20 kWh.
- PGS 37-2 applies to the storage of lithium-containing energy carriers (cells, batteries or batteries) as listed in Table A of Chapter 3.1 of the ADR. The lower limit of applicability of the PGS 37-2 is 333 kg energy carriers per fire compartment.

Implementation PGS

PGS guideline describes the main risks of the activities, as well as goals and measures to achieve the goals for (1) the safety and health of workers (2) safety of the environment (3) fire safety

PGS gives substance to the

- **Environmental safety/ Firefighting Environmental safety:** Preventing unusual occurrences and limiting their consequences for the environment with a view to ensuring safety for the environment
- **Occupational safety**: Preventing accidents involving dangerous substances and limiting their consequences and preventing workers from exposure to dangerous substances
- **Fire and Disaster Response**: Limiting the consequences of a fire or disaster and ensuring effective disaster response.

The consultation round closed 7 April 2022, currently update is being made based on the received feedback. The result is expected to be completed by the end of 2022. The PGS 37 is integrated into the legislation as:

- **Direct working rule** - A PGS directive must be complied with in the Living Environment Activities Decree, insofar as it is aimed at ensuring safety for the environment (Ministry of Infrastructure and Water Management determines in consultation with the Ministry of the Interior and Kingdom Relations)
- **Designation** - PGS guidelines are designated in the **Decree on the Quality of the Living Environment** as information documents on the best available techniques (BAT) by the Ministry of Infrastructure and Water Management. The competent authority is then obliged to take PGS guidelines into account when granting an environmental permit for an environmentally harmful activity when determining BAT
- **Policy Rule** - Parts of the PGS guidelines that are seen as state of the art and professional services are included in the policy rule to meet goals for occupational safety. (Ministry of Social Affairs and Employment)
- **Guideline** - The safety regions use the PGS guidelines as a guideline when advising on fire safety in environmental permits and when preparing fire and disaster response
- **Reference framework** - The supervisory authorities of the competent authority, the Inspectorate SZW and the safety regions consider the PGS guidelines to be an important reference framework when monitoring compliance with legal obligations, such as the Seveso Directive.

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[29] NEN 4288 Bedrijfsvoering van batterij-energieopslagsystemen aanvullende eisen NEN3140 https://normontwerpen.nen.nl/Home/View/157238

[30] Circulaire risicobeheersing lithium-ion energiedragers, https://wetten.overheid.nl/BWBR0043769/2020-07-01

[31] PGS 37, https://publicatiereeksgevaarlijkestoffen.nl/publicaties/PGS37.html

Although neither of the two parts are formally applicable, DNV recommends including the BSS in the scope of the PGS 37, since the technology is related, the risks are similar and the PGS will fit logically in the existing legal framework.

5.4 Legislation in Norway and Germany

Currently, there is no European member state with specific legislation for battery swapping stations. Also, a list of requirements or standards that a system needs to comply with is not available.

Battery swapping stations within Europe are not only being built in the Netherlands, but also in Germany and Norway In some countries, the construction of a BSS can be started during the permit application phase. It is not specified in the permitting legislation to which stage or how far the BSS can be constructed. The risk of dismantling or removal of a system when permit is not handed out, is for the BSS builder. This approach is not recommended, because (1) required safety measures during construction phase should be in place; (2) it is difficult to do any adjustments or incorporate permit requirements during the construction stage.

In case the PGS 37 would include a specific section on BSS or the competent authority has a clear list of requirements/ standards, the process is much more transparent for all parties and the lead time of the permit process would be significantly reduced.

6 GAPS IN REGULATION AND RECOMMENDED ACTIONS

6.1 Gaps in safety regulation

There is no Dutch regulation in place specifically developed for battery swapping stations, although a BSS fits under the Circular as lithium-ion energy carrier. A BSS also falls within the definition of PGS 37-1 according to the standard preparation committee. PGS 37-1 is expected to replace the Circular in 2023, but there is no additional typical system configuration (defining a BSS) in the making so far.

EU regulation requires CE marking, however there is no harmonized standard that can be used. In absence of a harmonized standard, IEC standards can be used to show so-called presumption of conformity; for this the IEC 62840 series contains the relevant items. The EU regulations and directives do not require an independent review of the BSS design, the CE marking is a self-declaration.

6.2 Regulatory recommendations

DNV recommends taking the following actions:

- Create an extra category (so-called Typical) scenario in the PGS regulation, addressing the BSS. The risks and mitigation measures are most similar to PGS 37-1, Typical 1, since this concerns a storage container where a person can enter the container. However, Typical 1 is usually placed close to a wind or solar park, while the BSS can be located in the building environment. Also, added requirements about the accessibility of the car should be added, such as never lock the car, and the driver should always be able to exit the car and leave the room safely, especially during the swapping process.
- A compliance checklist as part of the permitting process is needed to support developers, system integrators and manufacturers.
- Create a guideline/ helpdesk with knowledge about the BSS, to support the local competent authority with questions about BSS permitting requests. This can be either be organized by, for example, NAL or NIPV.
- Support finalisation of pre-standard IEC 62840-3 into a final standard, preferably harmonized under an EU Directive, so that it can be used in CE declaration to provide “presumption of conformity”.

- Create protocol for incident management and first responders including, e.g., specific risks, how to deal with passengers/driver in the car, accessibility etc

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Battery swapping is a technology that is growing rapidly in the Chinese market and heading towards the European market. NIO, an EV manufacturer based in China, has established ten battery swapping stations in four European countries. There are several other companies aiming to developing swapping stations and enter the European market too, which requires a careful look at the current standards and regulations for battery swapping stations (BSS). The main risks can be categorised into: mechanical, electrical, thermal, fire, data communication and cooling system risks. The current IEC standards for battery swapping stations outline these risks sufficiently and propose safety measures to mitigate anticipated risks. DNV was unable to verify if the BSS currently in the European market are compliant with the applicable IEC standards.

Various European and Dutch legislation applies, but none is specific for BSSs. Hazards exist, related to mechanical, electrical, cooling system and fire safety, that may therefore not be fully addressed by measures covered in regulation. BSSs are quite similar to a Battery Energy Storage System (BESS) in terms of construction, components and monitoring; BESS regulations such as the upcoming PGS-37 in The Netherlands are therefore a good starting point but should be updated to be specific for BSSs.

7.2 Safety recommendations

- **Mechanical safety** is specific for BSS systems, since grid-connected battery storage systems have neither moving / rotating parts nor regular exchange of battery packs. However in BSSs, battery packs are frequently exchanged, potentially 500 – 2000 times over its lifetime. Therefore, various mechanical safety measures should be taken:
    - proper alignment between the battery and the vehicle
    - electrical disconnection/ connection should be synchronised with mechanical disconnection/connection
    - mechanical transfer devices should be anti-corrosive, water/ dust/ gravel resistant, reliable/durable, and operationally safe
    - prevention and detection/mitigation of wear and tear of the battery locking/ unlocking mechanism

- **Electrical safety** for BSSs is similar to grid-connected battery energy storage systems. Apart from the low voltage risks, which require proper grounding and shielding to provide touch safety (Dutch: *aanraakveiligheid*), wear and tear at the electrical connection point between the battery and the EV due to swapping requires specific mitigation measures. Furthermore, rainwater, snow, salt air or dust should be preventing from entering the vehicle electric system and the battery.

- **Cooling system safety** in BSSs requires additional mitigation compared to battery energy storage systems, because of the frequent (dis)connection. Safety measures are needed to prevent and detect leakages as well as mitigating the effects, for example to ensure that a connection point is above a drip tray.

- **Fire safety** risks for BSSs are similar to the risks of battery energy storage system. Special attention should be given to the fact that a driver can be in the car, who needs to exit the facility in case of an emergency, as well as the presence of the BSS in the built environment. Thermal runaway is difficult to stop once it has started, but several levels of safety can prevent thermal runaway and mitigate the impact:

- Prevention: BMS monitoring: battery packs shall[32] always be monitored, also in storage and during charging. In this way, the status of the battery is always known.
- Early warning systems (sensors and detection): different sensors can detect early stage of thermal runaway, e.g. off-gas sensors, smoke detection, CO detection, hydrogen detection and temperature sensors. A detection system shall be used to detect issues in an early stage. 24-hour remote video monitoring (CCTV) could support a proper assessment of the status of an incident.
- Fire isolation: in the battery swapping room persons can be present. It is therefore recommended to separate the battery storage and charging station from the swapping room with a fire-retardant wall.
- Fire suppression system (FSS): since a BSS will often be placed close to occupied buildings, it is mandatory to implement a fire suppression system as per PGS 37-1. Although an FSS cannot stop a thermal runaway, it can ensure that external fires will not start a battery fire. Also, most FSS provide effective cooling, so the fire propagation is limited.
- Emergency response: the risk of the BSS is that a person is present in the car during an incident in the swapping process. It is therefore important that (1) the car driver and operator should always have access to emergency stop buttons (2) the car is always accessible from outside as well as from inside (3) driver/passengers should always be able to step in/out of the car while swapping is in progress, without any safety risks (mechanical and electrical shielding). If this is not possible, then all people should be out of the car during the process. (4) Emergency response plan is mandatory.

7.3 Other recommendations

The recommendations in this section support safe adoption of new battery swapping station technology:

- Regulation – Implement national guidelines on the permitting process for BSS, so all stakeholders have clarity on the requirements (competent authority, developer, landowner, etc). The easiest way to implement this is to create an addendum or specific category into the PGS 37, since the safety risks of the BSS are to a large extent similar to the Li-ion storage safety risks.

- Technology improvements – Ensure that there is feedback in which new lessons learned and insights are incorporated into the regulation, since the technology is still in development.

- Knowledge desk – A single point of contact for battery swap stations within the government authorities supports the alignment of local requirements and ensures that the competent authority has the knowledge to make decisions on the risks of a BSS, leading to a faster permitting process. A list of standards to which the battery swap system must comply can support this.

- DNV views IEC 62840 (regarding safety and interoperability of battery swap systems) as a good basis for safety measures for BSS. Part 3 is a pre-standard, to be turned into a final standard by the TC 69 committee on electric vehicles. The next step is that the CEN/ CENELEC harmonizes the standards, so that it can be used in the CE declaration to provide “presumption of conformity”.

- Create protocol for incident management and first responders including, e.g., specific risks, how to deal with passengers/driver in the car, accessibility etc

[32] The first two safety recommendation bullet points are requirements in IEC, UL and PGS standards/regulations.

APPENDIX A
Abbreviation list

Term	Description
ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road
ARBO	Arbeidsomstandigheden (working conditions)
Baas	Battery-as-a-service
BAT	Best available techniques
BCU	Battery control unit
BEV	Battery electric vehicle
BMS	Battery management system
BSS	Battery swapping station
CCTV	Closed-circuit television.
CE	Conformité Européenne
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CO	Carbon monoxide
DC	Direct current
EMC	Electromagnetic compatibility
EMS	Energy management system
EV	Electric vehicle
FCR	Frequency containment reserve
FSS	Fire suppression system
HMI	Human machine interface
IEC	International Electrotechnical Committee
IP	Ingress protection
LFP	Lithium Iron Phosphate
Li-ion	Lithium-ion
LVD	Low Voltage Directive
MD	Machinery Directive
NAL	Nationale Agenda Laadinfrastructuur
NEN	Nederlands Normalisatie-Instituut (Netherlands Standards Institute)
NMC	Nickel Manganese Cobalt
PGS	Publicatiereeks Gevaarlijke Stoffen (Publication series dangerous goods)
SCADA	Supervisory control and data acquisition
SoC	State of Charge (= actual energy content as a percentage of residual capacity)
SoH	State of Health (= residual capacity as a percentage of the original capacity)
SZW	Ministerie van Sociale Zaken en Werkgelegenheid
WABO	Wet Algemene Bepalingen Omgevingsrecht

APPENDIX B
List of applicable standards

Electric vehicle battery swap system

- IEC 62840-1 Part 1: General and guidance Technical Specification (2016)
- IEC 62840-2 Part 2: Safety requirements (2019)
- IEC 62840-3 Part 3: Particular safety and interoperability requirements for battery swap systems operating with removable RESS/battery systems
- GB/T 40032-2021 Safety requirements of battery swap for electric vehicles

Machinery directive

- IEC 60204-1: Safety of Machinery – Electrical Equipment of machines
- IEC 60204-32: Safety of Machinery – Electrical Equipment of machines; Requirements for hoisting machines
- IEC 61310-1: Safety of machinery - Indication, marking and actuation – Part 1: Requirements for visual, acoustic and tactile signals
- IEC 61496-1: Safety of machinery - Electro-sensitive protective equipment – Part 1: General requirements and tests.
- ISO 10218-1: Safety Requirements for Robots.
- ISO 12100-1: Safety of Machinery – Basic concepts, general principles for design – Part 1: Basic Terminology Methodology
- ISO 12100-2: Safety of Machinery – Basic concepts, general principles for design - Part 2: Technical Principles
- ISO 13849-1: Safety of machinery –Safety related parts of control systems -Part 1: General principles for design
- ISO 13849-2: Safety of machinery –Safety related parts of control systems -Part 2: Validation
- ISO 13850: Safety of machinery -Emergency stop -Principles for design
- ISO 13855: Safety of machinery - Positioning of safeguards with respect to the approach speeds of parts of the human body
- ISO 13856-1: Safety of machinery - Pressure-sensitive protective devices – Part 1: General principles for design and testing of pressure-sensitive mats and pressure sensitive floors
- ISO 13856-2: Safety of machinery - Pressure-sensitive protective devices – Part 2: General principles for the design and testing of pressure-sensitive edges and pressure-sensitive bars
- ISO 13856-3: Safety of machinery - Pressure-sensitive protective devices – Part 3: General principles for the design and testing of pressure-sensitive bumpers, plates, wires and similar devices
- ISO 13857: Safety of machinery -Safety distances to prevent hazard zones being reached by upper and lower limbs
- ISO 14118: Safety of machinery - Prevention of unexpected start-up
- ISO 14121-1:2007 Safety of machinery - Risk assessment - Part 1: Principles
- ISO 19353:2016 Safety of machinery - Fire prevention and fire protection

Electrical safety/ low voltage directive

- HD IEC 60364 Low-voltage electrical installations (All parts)
- EN IEC 60664-1:2007Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests
- EN IEC 60664-4:2005Insulation coordination for equipment within low-voltage systems - Part 4: Consideration of high-frequency voltage stress

- EN IEC 61140:2016 Protection against electric shock - Common aspects for installation and equipment
- IEC 61558-1: Safety of power transformers, power supplies, reactors and similar products – Part 1: General requirements and tests; applies in conjunction with IEC 61558-2.
- IEC 61984: Connectors - Safety requirements and tests

Electromagnetic compatibility directive

- EN IEC 61000-6-1 Standard for Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments
- EN IEC 61000-6-2 Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
- EN IEC 61000-6-3 Standard for Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
- EN IEC 61000-6-4 Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments
- IEC 61000-6-5 Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for equipment used in power station and substation environment
- EN IEC 62052-11 Electricity metering equipment - General requirements, tests and test conditions - Part 11: Metering equipment
- EN 50160:2010 Voltage characteristics of electricity supplied by public electricity networks

Functional safety

- IEC 61508-1 Functional safety of electrical/electronic/programmable electronic safety-related systems
- IEC 61511-1 Functional safety - Safety instrumented systems for the process industry sector - Part 1: Framework, definitions, system, hardware and application programming requirements
- IEC 61800-5-2: Adjustable speed electrical power drive systems -Part 5-2: Safety requirements – Functional
- IEC 62061: Functional safety of safety-related electrical, electronic and programmable electronic control systems

Cyber security

- IEC 61850 Communication networks and systems for power utility automation (Series)
- IEC 62351 - Power systems management and associated information exchange - Data and communications security (Series)
- IEC 62443 Industrial communication networks - Network and system security / Security for industrial automation and control systems (IACS)

APPENDIX C

Circular on risk management of lithium-ion energy carriers

The following are recommendations from the Circular (not from this study):

Cell and Battery:

1. Recommendations on manufacturing are out of scope. Compliance with the international requirements for transportation safety must be proven: UN 38.3 compliance (mandating test reports) and ADR compliance.

Designing and setting up a BESS:

2. Use materials that do not contribute to fire propagation.
3. Modular setup: design a BESS in such a way that overheating and/or self-ignition of an energy carrier is limited to a single battery module (max 15 to 20 kWh). Requirements are deemed fulfilled if IEC 62619 and IEC 62933-5-2 standards are complied with.
   - IEC 62619 specifies requirements and tests for the safe operation of secondary lithium cells and batteries in industrial applications (incl. stationary applications).
   - IEC 62933-5-2 specifies safety requirements for grid-integrated electrochemical-based ESS system.
4. Offering the possibility of an inspection by the fire brigade and/or competent authorities is recommended, as is making available safety-related information to the same.
5. It is remarked that adequate climate control and ventilation can prevent overheating of the room in which the BESS is placed. No recommendations or requirements added.
6. Lightning protection system as per IEC 62305-3 level III or IV.
7. Implement vehicle barriers if the BESS is <10m of public road(s), or for mobile BESS if there is a risk for vehicle collision.
8. Thermal detection and carbon monoxide detection are both recommended, with forwarding to a private emergency center. For mobile BESS forwarding to a construction site manager or event organizer is recommended.
9. If no mitigation measures for fire propagation outside of battery modules are implemented, arrangements for alternative containment and suppression measures are recommended. This may include water or aerosol-based fire suppression, if certified and proven capable to suppress a Li-ion fire in its early stages.
10. A 'storz' coupling on a BESS's energy carriers' compartment (with dry pipes installed to direct the water to the battery packs) is considered an optional 'last line of defense'. If sufficiently demonstrated that there is no fire propagation outside of battery modules, a 'storz' coupling is deemed redundant. When a 'storz' coupling is implemented, the compartment should include an overflow for surplus water and enable all energy carriers to be completely submerged.
11. Means of discharging (i.e. collecting outflow of) polluted water - from cooling or fire extinguishing – should be discussed with the public body responsible for incident management (Dutch: 'Veiligheidsregio').
12. Indoor BESS should provide for extraction of the flammable and corrosive gases from a Li-ion incident. Persons in the building shall not be exposed to the gases.

Surroundings:

13. Selection of a location should incorporate an assessment of a potential fire incident and formation of toxic fumes (incl. prevalent wind direction). The absence of a modular setup (see pt 3) puts more emphasis on proper site selection.
14. Risks for surroundings of a BESS focus on 'vulnerable objects or buildings and locations', e.g. homes, densely occupied offices and event sites. Special care should be given to 'very vulnerable buildings' as detailed in Annex VI to the decision on quality of the environment[(1)] (Dutch: 'Besluit kwaliteit leefomgeving'), including 24h care facilities, elementary schools, etc.
15. Proximity to population centers should be avoided if possible. This relates to the size of the BESS and strictness of the safety measures and protocols.
16. Proximity to emergency exits or regular exits is discouraged, especially when it concerns large groups of people. For event sites a BESS should be placed at the edge, with easy access for emergency services.
17. A distance of 5m between BESS and surrounding buildings is advised, also if a modular setup (see pt 3) and fire protection measures are present.
18. An indoor BESS is not preferred but can occur. A modular setup (see pt 3) is even more relevant (for incident containment) for indoor BESS.

Accessibility and information:

19. The public body responsible for incident management (Dutch: ‘Veiligheidsregio’) should be notified of presence and relevant details of the BESS.
20. Access to the BESS by emergency services should be guaranteed, and sufficient space should be available for the fire brigade and its equipment, considering a safe working distance.
21. Warning signs and markings indicating the nature of the BESS should be applied on the outside.
22. Good housekeeping should be adhered to. Including remote monitoring of the BESS, emergency response plan, emergency procedures, and a shut-down of the BESS (excl. safety measures) at dangerous irregularities during operations.

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