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Report
EU Energy Storage Systems Safety Conference 2023

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Introduction

On November 8th and 9th 2023, the EU Energy Storage Systems Safety Conference took place at the Netherlands Institute for Public Safety (NIPV). During this conference, the safety of Energy Storage Systems (ESS) was discussed, as well as their role in the energy transition and the scientific background on how energy storage with batteries actually works. The first day consisted of eleven inspiring talks around these topics, given by speakers from the UK, Sweden, the Netherlands and the US.

On the second day, the attendees visited different organisations dealing with energy storage systems at the IPKW site (Industriepark Kleefse Waard) in Arnhem. This document gives an overview of the first and second day of the conference and summarizes key information on the state of the art of ESS and their safety.

1 Wednesday 8 November – Lectures

1.1 Opening (IJle Stelstra)

The first day was opened by IJle Stelstra, director of NIPV. IJle stressed the importance of scientific research, data and facts concerning the energy transition in order to stay away from speculation.

Figure 1.1 IJle gives his talk

1.2 Maintaining the electrical balance of the grid, using batteries (Mark Dijkstra - TenneT: Batteries: security of supply & safety)

The first presentation was given by Mark Dijkstra, a Process Specialist for balancing the electrical grid at TenneT. TenneT is one of the largest grid operators in the Netherlands and Europe, and is responsible for the electrical network not only in the Netherlands, but also in a large part of Germany. Besides providing a robust and efficient high-voltage grid and facilitating the electricity market, the grid operators are responsible for maintaining the balance of electricity around the clock. ‘Balancing the grid’ means the amount of energy produced matches the amount of energy consumed. Maintaining that balance becomes especially challenging when the energy transition leads us from using predictable, on-demand energy production from for example coal and gas, to applying fluctuating energy sources such wind and solar. To even out such fluctuations in energy production and maintaining grid balance, surplus energy can be stored in large battery packs and reintroduced to the system when consumption is higher than production. Large battery packs with Lithium-ion batteries are a nearly ideal technology to achieve this as they can be charged and discharged when needed. Mark illustrated this concept by elaborately discussing an incident during which a wind park had to be shut down due to bird curtailment, which caused an immense, unexpected imbalance of the grid. This imbalance was resolved with the use of energy stored in batteries.

He finished his presentation by stating that energy storage, regardless of the way it is done (batteries, hydrogen, natural gas, water dams), poses an intrinsic risk and has to be carried out in a safe manner. A big accident involving a ‘new’ technology can influence the trust in that technology negatively and hinder or even stop the development of an upcoming market. Safety should therefore be one of the main concerns when developing and applying energy storage technologies.

Figure 1.2 Mark gives his presentation

1.3 Thermal Runaway incident in a 20 MW Battery Energy Storage System (John O’Boyle - Group Manager, Merseyside Fire & Rescue Service in ESS Liverpool)

John O’Boyle, a group manager at the Merseyside Fire & Rescue Service in Liverpool (UK) discussed the risks of working with large battery systems. He discussed an incident on Carnegie Road in Liverpool, involving a 20 MW BESS for support of the national grid. On the 15th of September 2020 at 1 am, the fire and rescue service received reports of explosions on the BESS site. Specifics of the BESS were unknown beforehand One of the three battery containers had caught fire after thermal runaway of one of the battery modules. Pressure had built up inside the container, leading to deformation of the container, followed by a deflagration blowing away the container doors. Debris was spread around the incident site as far as 22m. Hydrogen fluoride and hydrochloric acid were released in plumes, which spread in the air even with little wind impact, fortunately limiting the spread of the hazardous substances in the surrounding areas. Copious amounts of water were used to extinguish the fire and the fire brigade had to attend to the accident for a total of 59 hours.

Various valuable lessons can be learned from this incident. Large battery packs should be placed at a substantial distance from buildings and other packs to avoid fire propagation. Due to the high voltage and explosion hazard, the battery units should not be entered. Battery fires are extremely hard to extinguish; hence the fire service should consider letting battery fires burn out instead of trying to extinguish them (fight fire with fire). When dealing with battery accidents, the focus should be laid on protecting the surroundings and keeping the temperature as low as possible.

Once a BESS system is installed, it is highly recommended to provide the important information to the emergency services, such as buildings plans, details of key personnel, evacuation strategies, emergency access points and details of fire safety systems.

Figure 1.3 Presentation given by John

1.4 Fire in the battery room of a hybrid river cruiser (Jetty Middelkoop - Hazmat officer, Fire Dept. Amsterdam Amstelland)

In order to promote the safety of BESS, we need to learn from incidents involving batteries. Jetty Middelkoop, Hazmat officer at the Fire Department of Amsterdam, shared such an incident with the audience. Fire and explosion were reported, originating in the battery room of a cruise ship that was anchoring at the Ruijterkade in Amsterdam. The crew had opened the battery room to investigate a reported malfunction, but closed and abandoned it after discovering the flames. The fire department was alarmed, and the ship evacuated. The biggest danger when dealing with a malfunction in a battery room, is the accumulation of flammable gasses in the room, potentially resulting in an explosion. Right after the incident there was no reliable information about the gas concentrations in the battery room, nor could the battery status or the ventilation be checked from the control room. To further complicate the situation, it was unclear if the installed extinguishing system of the battery room had activated and if it was effective against battery fires. Overall, the risk of opening the door of the battery room was too high and it was decided to keep the door closed until a solution could be found after consulting the supplier of the battery. On the second day, after careful consideration, firefighters with self-contained breathing apparatus (SCBA) equipment had to break open the door. Fortunately, the gas concentration was low enough to be safe, and the incident could be investigated. It was found that an electrical problem in the battery control unit (BCU) had lead to thermal runaway of one of the battery modules.

In this case the emergency personnel had had no choice but to open the battery room without certainty that it would be safe. The incident exemplifies the importance of being able to measure gas concentrations in the battery room from a safely situated control room, control ventilation and check the status of the modules. It is also highly important that the fire department is informed of the specifics and the suppliers of all features in the battery room, such as the ventilation, extinguishing system and battery modules themselves.

Figure 1.4 Jetty explains the incident

1.5 My journey to vapour cloud explosions and lithium-ion batteries (Paul Christensen - Professor, Newcastle University)

What exactly happens during a thermal runaway? Paul Christensen, Professor for Pure and Applied Electrochemistry at Newcastle University and founding director of Lithiumionsafety Ltd Consultancy, shed light on the topic and shared the insights of the research he and his team did on vapour cloud explosions (VCE). In January 2020, the team started with the first battery ignition test, exploring what happens when batteries are subjected to heating, nail penetration, crushing and overcharging. They found that a damaged battery generally first releases a white vapour that often catches fire, which was until then considered the biggest hazard. They also discovered that batteries with a low state of charge are just as hazardous as batteries with a high state of charge. Perhaps their most important finding was that when the vapour (consisting mainly of CO, H_2, SO_2 and NO_2) does not burn, a violent vapour cloud explosion can take place, which is now widely considered the most significant safety hazard associated with batteries. This has important implications for the way battery fires should be handled. Christensen states that anything that fights the fire but does not stop thermal propagation, changes the hazard from fire to explosion.

He finished his talk by sharing various examples of battery explosions and fires from all over world. He emphasized the importance of testing batteries by independent parties before entering the market, instead of blindly believing in safety claims made by producers.

Figure 1.5 Paul during his presentation

1.6 ESS Explosion Control (Matthew Paiss - Technical advisor, Pacific Northwest National Laboratory)

In his talk, Matthew Paiss discussed the importance of explosion control in BESS. With the increase in BESS systems, safety becomes a bigger concern. Battery safety of batteries is a systems approach; therefore, a database is kept: the EPRI Failure Database, a database for BESS failures.
Reducing explosion risks is the key gap. Therefore US regulation (NFPA 855, explosion control) is set up and updated to ensure safe batteries that can also be installed in houses. In the case of a BESS fire incident, it may thus be preferable to take a defensive firefighting approach while instead preventing the deflagration risks. There are three main ways to approach this:

\> Deflagration Venting (NFPA 68).
A passive system based on blow-out panels, dependent on the gas production. This system only provides protection during the explosion and does not necessarily lead to safe gas concentrations inside. However, it is a cheaper and easier option than deflagration prevention, and first tests with such a system (Intellivent) suggest that it is a viable option for outdoor BESS.

\> Deflagration Prevention (NFPA 69).
An active exhaust system that keeps the concentration below 25 % of the LEL. The sensors however are expensive and difficult to maintain. Furthermore, they can be sensitive to other

gases and fouling. Also, fire may damage the system, which makes the long-term functionality questionable.

> A specially engineered cabinet.

This cabinet ensures that no pressure waves are produced and no projectiles ejected.

Figure 1.6 Matthew gives a talk about ESS explosion control

1.7 Guidelines for the fire safety of BESS (Jonna Hynynen – Researcher, RISE Research Institutes of Sweden)

The Research Institutes of Sweden (RISE) aim to produce guidance regarding the fire safety of BESS. Therefore, Jonna Hynynen explains a project that has been set up, that aims to move away from capacity- based guidelines towards application-based guidelines. A second goal is to set up national guidelines. The project started with a literature study of incidents. However, serious incidents with BESS are rare and therefore limited data are available.

The guidelines can be summarized as follows:

> In Sweden, the owner of electrical installations is responsible for safe operation and installation, which should be done by authorized personnel.
> For BESS exceeding 600 kWh, a risk analysis should be done. This analysis should also be done for BESS in locations or for applications that require a high degree of protection.
> Thermal propagation between different units should be prevented by evaluating and testing.
> Systems that prevent propagation, such as ventilation and (fixed) extinguishing systems, are to be designed and tested on the specific installation for which they are intended.
> Fire & rescue services need to be trained in handling these electrical installations.

These regulations are published (in Swedish) in November 2023.

Figure 1.7 Jonna talks about guidelines around BESS safety

1.8 Safety and regulation of stationary Li-ion energy storage systems (Rianne ‘t Hoen, Senior Consultant, DNV)

It is estimated that in 2050 68 % of our electricity will come from solar and wind power. These energy sources cannot deliver electricity on-demand. Therefore, Rianne ’t Hoen explains that we need electricity storage in the form of Lithium-ion BESS. The big challenge is how and when these systems should be realized.

Lithium-ion BESS consist of battery cells which are packed into modules. These modules are stored in racks and several of these racks can be installed in containers of different size. The main risk of these systems is thermal runaway, leading to toxic gas release, fire and explosions. The focus should thus be on stopping thermal propagation. However, it is important to remember that incidents can never be totally prevented.

BESS move towards larger capacities. Furthermore, the production shifts to the EU. To manage the risks, standards and regulations need to be kept up to date (they are lagging behind those of the US and Australia). Standards are agreements between stakeholders about a product, service or system and reflect a consensus. They can be normative or informative. Due to their nature, they are always lagging behind the latest technology. Regulations are meant to enforce a standard. In August 2023, the European Battery Regulation is published, which focuses on a green deal, harmonises product requirements for batteries and provides legal certainty for innovation and production of sustainable batteries in Europe (and beyond). A special European Commission directive is aimed at battery cybersecurity, trying to ensure that batteries cannot be controlled by malicious and unauthorized access. This directive will be considered in January 2024.

Figure 1.8 Rianne gives her talk

1.9 Lithium-ion Batteries: Variations in performance and safety (Mark Huijben - Professor, University of Twente)

Lithium-ion batteries have an enormous impact on technological innovation, and it is hard to imagine a world without them. However, there is much more to gain and develop in the world of battery technologies. Mark Huijben, Professor of Nanomaterials for Energy Conversion and Storage at the University of Twente in the Netherlands presented the latest developments on next-generation batteries.

There are various battery types, mainly based on Lithium-ions, such as LFP or NMC batteries. Battery producers are continuously aiming for higher energy densities, making it possible to store more energy in smaller spaces. This enables the use of batteries in many more areas. Batteries have been powering cars and trucks for years now and have recently been installed in large container ships. With higher energy density batteries, powered airplanes are almost within reach. The batteries with the highest energy density currently on the market store circa 300 Wh/kg. This year the first battery allegedly reaching 500 Wh/kg was presented.

Focussing on engineering the surfaces and interfaces in a battery is one of the most promising approaches when aiming to improve the performance of batteries. With the help of composites, coatings, dopings, electrolyte modification and control of morphologies in the battery the structural stability of the batteries can be increased, ion transport can be enhanced, and electrolyte decomposition can be avoided.

Another aim is building batteries based on sustainable materials, without the use of precious metals. The use of Sodium-ion batteries is an advancement in that respect, as sodium is more abundant than lithium.

Furthermore, several steps are taken in research on battery safety, with solid state batteries being one of the most promising recent developments.

To this end, the national research program BatteryNL (a collaboration of five Dutch universities together with industry partners, research institute TNO and two German institutes) was set up and aims to generate a better understanding of material interfaces, advancing battery technology and safety.

Figure 1.9 Mark talks about lithium-ion batteries

1.10 Safety of future batteries (Henk Brans – Researcher, NIPV)

Henk Brans started his talk with an anecdote to show that in times of demand, innovation thrives. In the 1970s, during the first energy crisis, the Netherlands started looking at ways to save energy costs. In 1985, Park Sonsbeek in Arnhem started using a water ram, a self-regulating pump driven by flowing water.

Nowadays, we are looking at energy storage solutions. BESS are suitable for this. One of the problems with batteries is their risks, mainly related to thermal runaway. These risks mostly come from the (flammable) electrolyte, although the energy density of the cathode also plays a role. New battery types such as new Li-on subtypes, Sodium-ion (Na-ion) and Redox-flow) try to alleviate these risks. New Li-ion subtypes can be based on solid-state materials. Although these batteries can still go into thermal runaway, a higher stability is likely and the process is expected to happen at higher temperatures, due to the absence of an electrolyte. However, in batteries with lithium metal subtypes, dendrites can form in the battery. Furthermore, lithium metal is reactive with water and air, leading to other risks.

Sodium-ion (Na-ion) batteries work on the same principle as Li-ion batteries; therefore the risks are comparable. However, the thermal runaway process is expected to be a bit slower.

Redox-flow batteries store the energy in electrolytes in storage tanks. These electrolytes are pumped through stacks, where the electricity is generated. Only a small part of the active materials is located in the stack, which means that a thermal runaway will not occur, since the heat generated is relatively small. However, the active substances are toxic, which makes leakage the primary concern. Furthermore, small amounts of hydrogen gas may be released in case of electrical failure.

Figure 1.10 Henk gives his presentation

1.11 Explosion Control Challenges at Lithium-Ion Battery Energy Storage Systems (Jens Conzen - Vice President at Jensen Hughes)

Jens Conzen told us about Li-ion battery safety. In these batteries, the anode and cathode are kept apart from each other by a separator. This separator is very thin and has a low melting temperature. Accordingly, shorting of the battery can happen relatively easily, leading to a thermal runaway in BESS. Since a BESS consists of many modules in a rack inside an enclosure, a thermal runaway can release large amounts of energy via its exothermic reactions. Aside from fire, toxic, flammable gas release is a very real risk during a thermal runaway. A 10-kWh battery can release up to 4000 litres of gas. When these gases accumulate, they can form an explosive mixture. Incidents with explosions have happened in practice.

The lesson that has been learned from these incidents is that explosion prevention needs to be provided. This can be done in various ways, though not all of these are possible. For example, chemical suppression and inerting is not practical and not effective in Li-ion BESS. Isolation is neither practical and has a maximum pressure it can contain.

One of the promising techniques is combustible concentration reduction. This active system works via a mechanical exhaust ventilation system. A gas alarm activates the explosion prevention system by diluting and exhausting flammable battery gases below 25 % of the LFL. By CFD modelling, optimal detection timing can be determined. Another option is passive deflagration venting, which protects the system from overpressure and potential damage from a deflagration. This is achieved by vent panels.

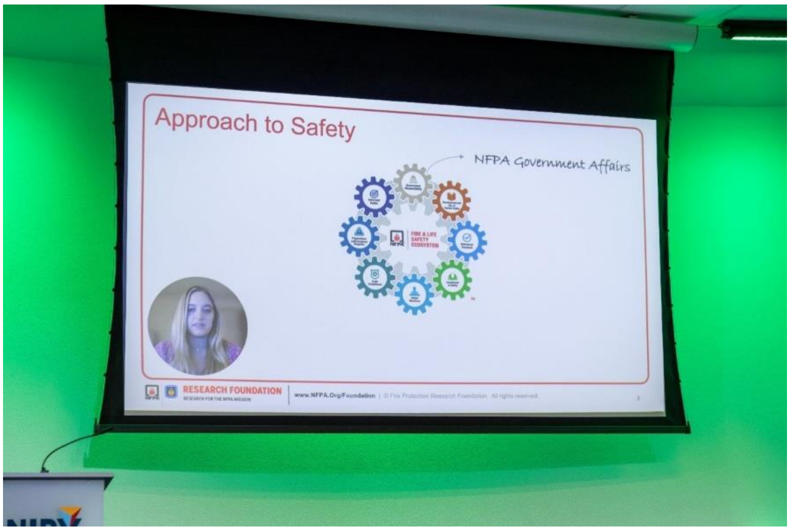
As there are pros and cons for each method, it is not expected that there will be a one size fits all solution. Solutions will depend on the design and location of the BESS, and of local safety regulations and emergency services.

Figure 1.11 Jens talks about challenges in explosion control

1.12 Guidance and Considerations for Safe Energy Storage System Installations and Incident Response: A US Perspective (Victoria Hutchison - Senior Research Project Manager, Fire Protection Research Foundation)

Victoria Hutchison, who unfortunately could not be there in person, told us about the Fire Protection Research Foundation (FRPF). They carry out research for the National Fire Protection Association (NFPA). The NFPA uses this research to set up standards and guidelines. The goal of these standards is to protect the community, via preventions or managing an incident. One way to manage the impact is via sprinklers. Separation distance and explosion control are other ways to mitigate the impact of an incident.

One of these standards is the NFPA 855 standard, which applies to the design, construction, installation, commissioning, operation, maintenance and decommissioning of Stationary ESS. This standard also sets a limit to the maximum stored energy. The standard differs, depending on the location of the BESS (outdoors or indoors). Furthermore, the allowed amount of stored energy is limited when the system is close to other structures.


Approach to Safety

NFPA Government Affairs

Figure 1.12 The online presentation by Victoria

1.13 Closing (Nils Rosmuller - Applied professor energy and Transport safety, NIPV)

The day was closed by Nils Rosmuller. He used this opportunity to pay attention to two topics that were mentioned in a number of talks and could be the focus for further investigation. First, he mentioned the safety of small batteries, such as the ones applied in bikes and electric scooters. Considering their size, they do not pose as big a risk as large battery packs. However, they can be found in large quantities in households, are most likely stored and charged indoors without ventilation, and are handled with less care and under less strict regulation. Therefore, they have been causing a number of incidents in the past. Making citizens aware of the risks presented by small batteries is crucial to avoiding accidents.

The second topic he mentioned was battery recycling. All batteries have a limited lifetime. We need to establish strategies to deal with batteries that are no longer fit for use, especially concerning questions how to deal with the hazardous substances and how to reuse the precious metals in the batteries.

Figure 1.13 Nils gives some closing remarks

2 Thursday 9 November: field trips

2.1 Connectr

Arnhem is home to well-established energy companies such as Alliander and the grid operator TenneT. Close to the town, the Industrial park Kleefse Waard (IPKW) is providing infrastructure to a number of successful start-ups. Connectr unites these companies and organisations and helps to bring safe products to market. Their aim is to build an ecosystem in which innovations can be made and where collaborations are encouraged, and also to provide a space to explore new ideas. The company's motto – 2030 is tomorrow – emphasizes the need for a fast energy transition and commitment to the EU's goal to drastically reduce greenhouse gas emissions by 2030 and reach climate neutrality by 2050. At Connectr companies can exchange their ideas, helping them to implement technologies faster. The presenters not only provided the participants of the symposium a glimpse into the way the organisation works and what its goals are, but also an opportunity to introduce themselves and share their goals and ideas.

Figure 2.1 Presentation by Connectr (picture: Cosima Stähler)

2.2 ElaadNL

Currently, around 7 % of the Dutch fleet consists of electric cars and there are around 10.000 public EV charging points in The Netherlands. This has a significant impact on the electricity grid and this impact is expected to grow with the increasing number of electric cars (around 43 % of newly sold cars are plug-in hybrids or fully electric cars). These charging

points are decentralized, meaning that we move away from a centralized situation of energy distribution.
ElaadNL is researching the impact of electric vehicles on the (Dutch) electricity grid. Their goal is to get to a smart and sustainable grid. A way in which ElaadNL tries to achieve this is via ‘Smart Charging’. This system tries to alleviate the stress on the grid by optimizing the charging of electric vehicles (EV’s) via public charging points during times when energy demand is low and/or renewable energy production is high. The grid is thus protected, and renewable energy usage is optimized. The protocol for this system is founded by ElaadNL.
ElaadNL also studies the effects of an (over)loaded grid on the charging of EV’s. Via supraharmonics, the power quality can be seen. An overloaded grid may lead to unwanted effects when charging an EV. ElaadNL has the capability to simulate an overloaded grid and uses this to test the effects on charging an EV.

Figure 2.2 Test lab of ElaadNL

2.3 Elestor and RIFT

Another start-up currently building a pilot plant on the IPKW terrain is RIFT. The company focusses on iron fuel technology. Iron powder is burned, forming iron oxide or rust and generating energy in the form of heat in the process, which can be harvested. The fuel can be repurposed by reaction with hydrogen, regaining the iron and forming water. In that way, iron acts as a very stable energy carrier, with substantially fewer risks to health and safety compared to other energy carriers. The application of iron as fuel is of especial interest to energy intensive industries.

Found in 2014, Elestor is one of the pioneers in Redox-flow batteries. These types of batteries are suitable for long-term and large-scale energy storage and therefore especially interesting for industrial applications. They are basically based on hydrogen and bromine. When charging the battery, hydrogen bromide is split into hydrogen and bromine, which can be stored on large scale. Forming hydrogen bromide from both compounds generates energy. Elestor has already realised a pilot-plant, which can be operated under real life conditions.

Figure 2.3 Hydrogen Bromide flow battery from Elestor (picture: Cosima Stähler)

2.4 DEKRA

The history of DEKRA lays in car inspections. Nowadays, one of the subjects DEKRA specializes in is battery thermal runaway testing to test to and update regulations. DEKRA tests battery safety by abusing a battery to see whether the safety systems kick in before the battery goes into thermal runaway. This propagation testing can be done via for example nail penetration, under- or overcharging, overheating and laser penetration. When the test fails, the battery will catch fire. Otherwise, the battery has passed the test. Preferably there will be no fire, explosion or deformation or rupture of the casing. The manufacturer can voluntarily subject his batteries to the tests.

Figure 2.4 Battery testing, as carried out by DEKRA

2.5 Brandweer Gelderland-Midden

Fire Brigade Gelderland-Midden hosted a session on how it deals with safety aspects of the energy transition. In their presentation, the fire brigade first elaborated on the way it is organized and how it tries to manage the risks of the energy transition. They also presented how the 25 fire brigades in The Netherlands work together in a nationwide program to support a safe energy transition. Part of this program is a public information campaign called ‘Veilig Huis Vinkie’ for a safe energy transition at home.

Figure 2.5 Demonstration by Brandweer Gelderland-Midden (picture: Tom Hessels)

In the second part of their presentation, the fire brigade showed several tools and methods for fire fighter training. One of these tools shows how electricity is conducted to make firefighters aware of the risks of electricity. Next to this, the fire brigade also presented a mobile mock-up of an Energy Storage System. This mock-up system can be used for fire fighter training. For example, a hose can be attached to the system to fill it with water.

Figure 2.6 Mobile ESS mock-up used for fire fighter training (picture: Tom Hessels)