

Overview of the Risks for Industrial-Scale Solar Power Generation

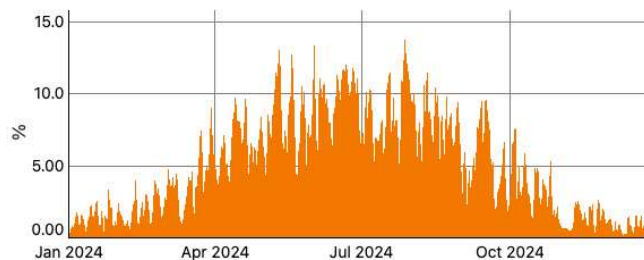
Introduction

Documentation regarding electricity generated using solar power usually only gives details of the benefits, without considering the associated risks. In fact, the majority of documentation, including planning applications from developers, does not acknowledge that there are any risks at all.

This document gives an overview of some of the risks that are associated with production using solar power when done at an industrial scale – when designed to only supply the national grid (The Grid). This document collates research done to consider individual risks and considers the risks from a system-wide point of view. It does not consider specific risk analysis, evaluation, or treatment, as these are related to the location, size, and detailed design of an individual site. For clarity, this document does not compare solar with other renewable sources of electricity or compare the effectiveness of solar compared to other options for renewable energy.

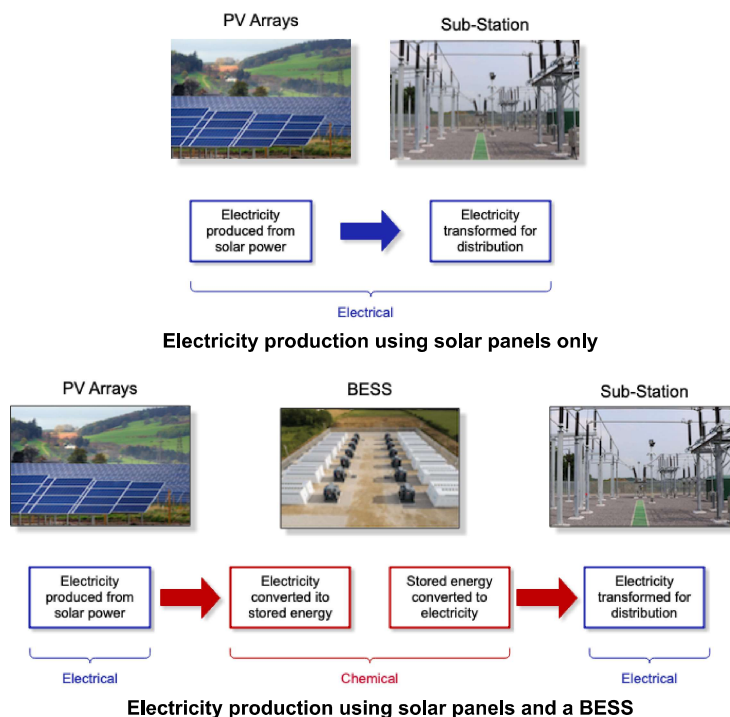
Solar Power Generation

Electricity is produced by solar power when sunlight is converted to electricity using photovoltaic panels (solar panels). However, solar power only works during the hours of daylight and, analysis of The Grid shows it only supplies a meaningful level of power to the grid during the summer.



Graph showing UK National Grid production from solar power during 2024 (showing % of total grid production)

To offset this disparity, a battery energy storage system (BESS) is used to store the electrical power produced and to release it when needed. A BESS is a large number of batteries that are charged from the solar panels and then discharged to provide electricity when required. When a BESS is used on a production site using solar power, the site must be considered as using integrated production methods, and the risks associated with all production methods used need to be considered.



While the relevant HMG Statutory Instrument state that Local Planning Authorities (LPAs) must consider the risk of major accidents and/or disasters and the risks to human health when considering a planning application for a development. In the UK there is minimal legislation or regulation covering industrial solar power, and there is no legislation or regulation covering BESS use. However, a bill to make consulting Fire and Rescue Services during planning applications a statutory requirement has had its first reading. To quote the section covering BESS safety in the HMG Research Briefing about BESSs:

“There are no laws that govern the safety of BESSs specifically.”

Lithium-Ion Batteries

The batteries most commonly used in a BESS are Lithium-Ion batteries (LIBs) – they are used in over 90% of BESSs in the UK. Due to their high storage density, this type of battery is also found in a number of common items including: mobile phones, electric bikes, and commercial power banks. Like all batteries LIBs can fail. However, unlike other battery types, LIBs can fail catastrophically.

The reason that LIB failures are so catastrophic is because of their design and how they fail. They use a chemical process where Lithium Ions are transferred in an electrolyte between two separate parts of the battery (Anode and Cathode) which are kept apart by a separator. If the electrolyte in a partially charged battery comes into contact with Oxygen it can explode. LIBs also contain both the accelerant and the oxidant for a fire – this means they do not require external Oxygen to burn and are effectively impossible to put out.

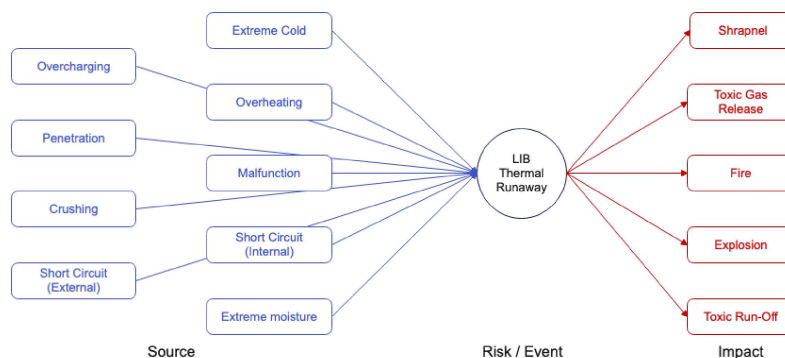
Because of this:

- LIBs are classed as dangerous goods when travelling by air and are banned from hold luggage in commercial aircraft.
- Electric bikes and scooters have been banned on the London Underground since June 2021 due to the risks posed by their batteries.
- The number of fires caused by LIB failures in the UK is increasing – the British Safety Council consider LIB fires a growing risk with a 46% increase in LIB fires in 2023 (921 LIB fires).

The primary failure method in a LIB is Thermal Runaway – a process in which uncontrolled chain reactions produce heat and continually cause an increase in battery temperature. As battery temperature increases, these reactions and other degradative processes occurring internally produce an even greater amount of heat, resulting in an uncontrollable rise in temperature (NB: this is NOT a fire and is a separate event). Thermal runaway is very difficult to monitor and manage. It should also be noted that the timescale for thermal runaway becoming a catastrophic failure can be measured in seconds.

The main failure modes for LIB are shown below. (NB: these are only related to LIBs, the failure modes for a BESS are described later.):

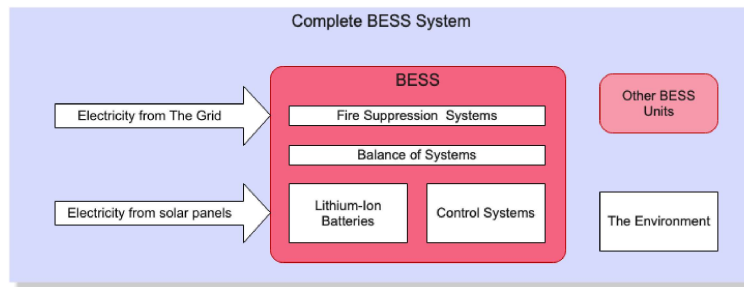
- Toxic gas release
- Fire
- Explosion



Bow-tie diagram for LIB thermal Runaway

BESS Failure Risks

The risks associated with a BESS should be considered for all stages of the system lifecycle and should include the BESS and its environment. Risks should also be considered as those that affect that BESS and those that are caused by the BESS. Therefore, the BESS should be considered as a complex system.



Overview of a complete BESS system.

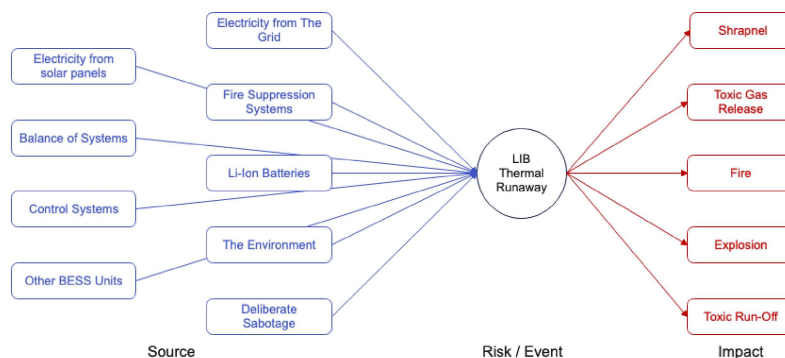
The LIBs in a BESS are arranged in modules made up of cells (a single battery), these are combined into racks, and a BESS is made up of a number of racks. This means that if thermal runaway occurs in a cell, it can rapidly spread through the module, then spread across the entire rack and the entire BESS. While this chain reaction is happening, the failure modes of each affected cell can also happen simultaneously.

Control Systems failure, and failure of other elements in the complete BESS system, can also be sources of risk. Failure of the Control Systems can result in any of the sources for thermal runaway happening. This can also be as a result of a loss of power to the site from The Grid, e.g. due to a localized power cut. (Note: Industrial scale power generating sites generally rely on external power sources for their operating power.)

The Balance of Systems are those elements that are used to manage the BESS, these include air conditioning, busbars, cabling, transformers. (Note: the air-conditioning needs to run constantly to keep the LIBs in their safe temperature range). For this document, Fire Suppression Systems are considered separately as they have specific risks to be considered. These include: not actually being able to detect a BESS failure, the system not actually being effective in managing the resultant BESS failure, or even creating risks. E.g. using water to suppress a fire can cause short circuits, may not reach cells in the centre of racks, and Lithium's high reactivity with water creating explosive Hydrogen gas.

The Environment can be a source of risks to a BESS, e.g.: the external temperature raising due to climate change, damage due to flooding, or other environmental effects. Effects to the environment from a BESS failure include the uncontrolled release of toxic gases into the atmosphere and the release of contaminated run-off from the BESS due to efforts to suppress a BESS failure. Environmental risks are particularly important to consider as they can have very wide-ranging effects and can be permanent.

Other BESS units must also be considered, as a failure in one BESS unit can affect neighbouring units. Particularly as one of the failure modes is an explosion of the unit, with accompanying shrapnel damage. While deliberate sabotage is not a part of the BESS system it is a risk, and includes physical sabotage to the equipment on-site and cyber-attacks. It needs including because industrial-scale electricity production is a part of the UK Critical national infrastructure.



Bow-tie diagram for a complete BESS system

Risks should be considered holistically and cumulatively. This should also include any risks related to containing and dealing with a BESS failure, or multiple BESS failures – either multiple BESS failures on a single site, and/or on multiple sites close to each other. For example, the risk to the BESS from flooding and the risk to the environment from toxic run-off can be thought of as being related and in tension: any mitigation of the flood risk will increase the effect of the toxic release risk, and vice-versa. E.g. a soak-away

to manage flooding will allow toxic run-off to enter the ground water more easily, whereas bunding to contain any toxic run-off will increase the risk from flooding.

The sources of a BESS failure are many and complex. Analysis of worldwide BESS failures has shown them to be due to the following system elements:

- Batteries (11%)
- Balance of Systems / Fire Suppression Systems (43%)
- Control Systems (46%)

Root Cause Analysis has shown that the majority reported BESS failures happen in the first 5 years of life. (Note: the life of a BESS should be taken from when it is built, not from when it is first used or connected to The Grid). Operation has been found to not be the main cause of BESS failure. Failures due to different lifecycles phases were found to be:

- Manufacturing (14%)
- Design (21%)
- Operation (29%)
- Integration, Assembly & Construction (36%)

It must be noted that the reluctance to release BESS failure data into the public realm means the available analysis is incomplete. Also, there is evidence that BESS units use LIB that are second life, i.e. they have already been used in another system, e.g. an EV, before being fitted into a BESS. This means that the actual situation may be much worse than is currently understood.

Summary

- A site with solar panels and a BESS uses electrical and chemical processes to produce electricity
- By law, LPAs must consider the characteristics of a development with particular regard to the risk of major accidents, the risk of disasters, and the risks to human health
- There are no laws that govern the safety of BESSs specifically
- Lithium-Ion batteries fail catastrophically
- Lithium-Ion batteries fires are effectively impossible to extinguish
- Failure of any part of a BESS can cause catastrophic battery failure
- A BESS can fail at any point in its lifetime
- Currently, the majority BESS failures happen in the first 5 years of life
- A BESS failure can result in:
 - Explosion of the Unit
 - Fire
 - Toxic Gas Release
 - Shrapnel
 - Toxic Run-off
- Thermal runaway can become a catastrophic failure in seconds
- There is a reluctance to release full and transparent data about BESS failures
- Risks should be considered holistically and cumulatively
- Mitigating one risk can make the impact of a related risk worse
- A BESS failure can affect a large area surrounding the BESS
- Extensive clean-up activities may be needed after a BESS failure.
- The effects of a BESS failure may be permanent

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