Elkhorn Battery Energy Storage System Fire of September 20, 2022

Public Report of Technical Findings

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Preface

This report is a technical review of the fire event that occurred on the 20th of September 2022 at the Elkhorn Battery Energy Storage System (BESS) located in Monterey County, California, as part of the Moss Landing Electric Substation. This report has been prepared for public use.

This report summarizes those investigations and analyses from all the entities involved and has been prepared by Energy Safety Response Group (ESRG), an independent energy safety consulting firm. The report provides a summary of lessons learned from this incident and highlights the procedural, equipment, hardware, and software changes that are being considered since the incident that have been, or will be, applied to all current or future Megapack installations.

I. Background and Event Overview

On Tuesday, September 20th 2022, at approximately 1:06 am PDT, a Megapack at the Elkhorn Battery Energy Storage System (BESS) experienced a thermal event and caught fire.

The Elkhorn BESS is located at the Moss Landing Electric Substation in Monterey County, California. The site is owned and operated by Pacific Gas and Electric Company (PG&E), and the equipment involved in the fire is a Megapack provided by Tesla, and maintained by Tesla under contract to PG&E. The site is a neighbor to the Moss Landing Power Station, operated by Vistra Energy.

Elkhorn BESS went fully online on April 7, 2022. The facility has the capacity to store and dispatch up to 730 megawatt hours (MWh) of energy to the electrical grid at a maximum rate of 182.5 MW for up to four hours during periods of high demand, enough to power 225,000 Monterey County homes.

The Megapack is a lithium-ion battery energy storage system consisting of battery modules, power electronics, a thermal management system, and control systems. The Megapack is a first-generation product and is sometimes also referred to as the Megapack 1 to distinguish it from second-generation of Tesla BESS called the Megapack 2. Elkhorn BESS is composed entirely of the Megapack 1, referred to herein simply as the Megapack.

The fire involved a single Megapack. The fire proceeded in accordance with its design and consumed itself. It burned as a flaming fire for about 6 hours, and then generated visible smoke and off-gas for another 12 hours. As per the instructions in Tesla's Lithium-Ion Battery Emergency Response Guide (ERG), which were incorporated into the PG&E Pre-Fire Plan, the Megapack was allowed to burn and consume itself while being monitored by first responders at a safe distance.

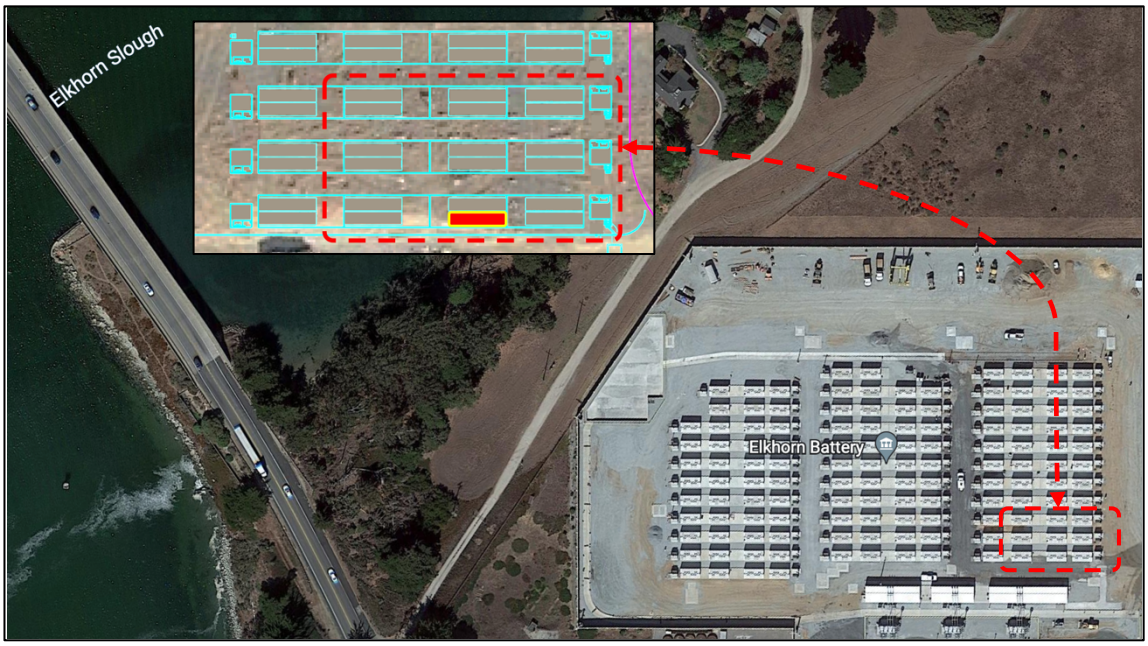

Figure 1: Overview of Elkhorn Battery Energy Storage System

II. Incident Timeline

The Elkhorn BESS fire occurred throughout Tuesday, 20 September 2022. It started soon after midnight and was considered controlled and out before the start of the next day. Applicable activity and conditions began several days prior to the fire. The timeline considers the following seven phases:

A) Pre-Incident (18-19/Sept/2022)
B) Alarm & Notification (20/Sept/2022)
C) Arrival & Initial Fire Operations (20/Sept/2022)
D) Stage 1 – Water Application to Exposures (20/Sept/2022)
E) Stage 2 – Water Re-Application to Exposures (20/Sept/2022)
F) Stage 3 – Extended Operations (20/Sept/2022)
G) Post Fire – Investigations & Remediation (21/Sept/2022 – 7/Oct/2022+)

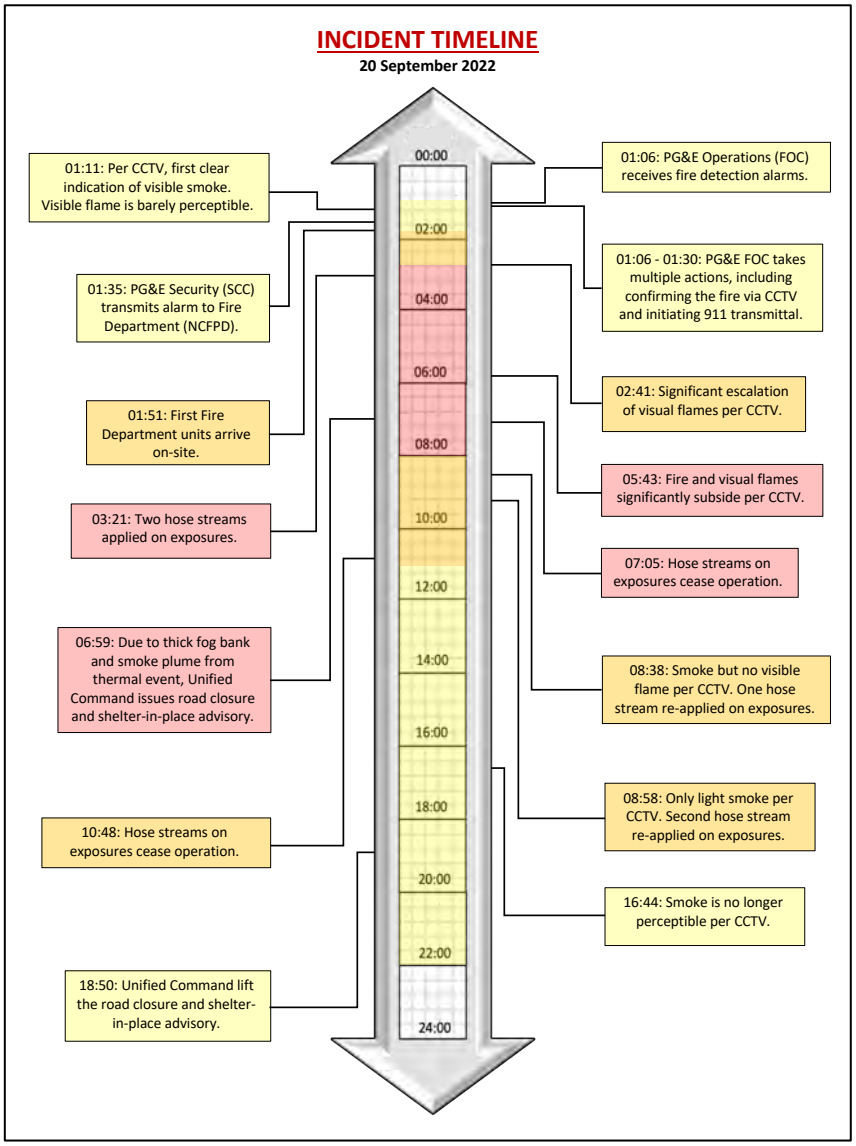

Figure 2: Incident Timeline for 20 September 2022
(Note: Figure shows Timeline Phases B though F only)

Notably, only the single Megapack involved in the fire was eventually removed from service and taken off site. The adjacent Megapack cabinets in the vicinity of the fire experienced minimal or no damage. Only the Megapack immediately behind the one consumed by fire experienced cosmetic damage, while other neighboring Megapacks had no damage from the fire. The Megapack that had the fire was a total loss, which had fully consumed itself as designed.

III. Investigation & Root Cause Analysis (RCA)

The investigation process was initiated in the days following the fire, and included PG&E, Tesla, local regulatory entities, outside third-party engineers, and various subject matter experts. The investigation process involved analyzing the fire cause and origin, as well as the emergency response to the incident from site personnel, local fire and emergency responders, and Tesla engineers/subject matter experts. This assessment has been performed by Tesla to identify any recommended changes for the design, operation, and maintenance of the Megapack equipment or the Elkhorn BESS.

The Root Cause Analysis of the incident identified the cause to be significant water ingress, which ultimately allowed electrical shorts to initiate the thermal runaway of the battery cells. Rainwater intrusion into the units was the result of displaced umbrella valves on the roof, displaced during the installation of new vent shields.

Significant water ingress ultimately allowed electrical shorts that initiated the thermal runaway of battery cells. The investigation has provided clear evidence of this cause. Other possible causes that could have resulted in thermal runaway of battery cells have been ruled out based on the lack of evidence that would indicate they had any influence on causing the thermal event. Immediate field inspections and modifications were implemented to inspect and correct all backward vent shields. Corrective measures have been identified for this and all related issues, and all have been implemented for Elkhorn BESS to prevent event reoccurrence.

In addition to the known issues involving water ingress, there were additional confounding factors that influenced the fire event during the Pre-Incident time frame, that is, the two days prior to the fire event. These included: (1) Auto-Safe Discharge; (2) Tesla Monitoring Alarm; and (3) Playbook Guidance.

- Automatic Safe Discharge (ASD) Feature. ASD, when triggered, allows the battery to discharge into other batteries in the pack at a safe rate to a level that is a proven threshold for safety and transport. Isolation loss is a trigger for it. ASD may have prevented the September 20 thermal event because ASD would have been completed hours before the fire event. The most current firmware version that included the ASD feature was not running at Elkhorn BESS. The latest updated firmware has now been installed and includes this feature.
- Alarm Update & Approval Process. The battery isolation failure alerts and associated server-side alarms were not elevated to the awareness of the Tesla operators. This was due to Tesla moving the battery isolation failure alarm to the staging environment for update due

to nuisance. Tesla is updating the alarm approval process for all firmware and software updates to always run the old version while a new version is being tested and installed.

- Playbook Guidance for Isolation Failure Alerts. The Playbook is the operational guidance document used between the facility operator (PG&E) and the BESS Equipment provider (Tesla). It is maintained by Tesla, and it provides specific actionable guidance for PG&E and Tesla operators to take based on specific alerts and alarms. The Playbook is being updated by Tesla to change the guidance for isolation point firing (i.e., redundant failure point) from "No Action" to "Contact Tesla for further guidance."

IV. Emergency Response

In the event of a propagating thermal runaway, the Megapack is designed to consume itself in a controlled manner without deflagrations and without propagating beyond a single cabinet. This minimizes the risk to any surrounding personnel during fire response and minimizes the risk to personnel from stranded electrical energy. This was the case at this fire as the event proceeded in accordance with its fire protection design, and presented no unusual, unexpected, or surprising characteristics, such as an over-pressure event or explosion.

The Elkhorn BESS resides within the jurisdiction of the North County Fire Protection District of Monterey County (NCFPD), which is the local fire department that responds to fire emergencies at this location. Often the Elkhorn BESS has no PG&E or other staff on site with the facility monitored remotely. This was the case at the initiation of the event when alarms were received at the Fresno Operations Center (FOC) that provides remote monitoring, which triggered notification of the NCFPD and response by PG&E personnel.

As per the instructions in Tesla's Lithium-Ion Battery Emergency Response Guide (ERG), which were incorporated into the PG&E Pre-Fire Plan, the Megapack was allowed to burn and consume itself while being monitored by first responders at a safe distance. The NCFPD effectively utilized this firefighting approach at the Elkhorn BESS fire, and consequently minimized unnecessary and dangerous risks to firefighters and site personnel.

The lessons learned from the emergency response to the Elkhorn BESS fire and recommended improvements and corrections are the following:

- Prioritization of Thermal Alarm Transmission. The first activation of the site's thermal detection indicating a potential fire event was received at the Fresno Operations Center among a multitude of other alarms and signals, indicating unexpected activity and a possible emergency event occurring at the unstaffed Elkhorn BESS. During the processing of all these alarms and signals, a time frame of almost one-half hour occurred before the NCFPD received notification via 911 of a potential fire. This time frame had minimal or no adverse impact on this fire event, though it relates to a larger on-going debate on the need for rapid, automated notification to local emergency responders upon initial activation of a fire event. Consideration should be given by PG&E to elevating the thermal detection alarms among the other alarms and alerts, and/or providing an automated alarm directly to the NCFPD and other entities.

- Incident Command Roles, Responsibilities & Training. The Elkhorn BESS is a facility that is often unstaffed, which is typical of such BESS sites and was the case at the time of the fire. PG&E personnel were dispatched to the site soon after the thermal event was realized, and key members arrived on-site in the first several hours of the event. During this event, the implementation of these roles & responsibilities by PG&E to support Incident Command was not clear. Fortunately, for this event the confusion on Incident Command had minimal adverse impact on the event outcome. Nevertheless, consideration should be given to the timely arrival of a knowledgeable PG&E personnel with appropriate Incident Command training, based on roles and responsibilities according to the Incident Command System. Specifically, consideration should be given to the timely arrival of a 24/7 PG&E Renewables Technician, that is assigned, trained and locally available to assume a command level role to interface with the emergency response Incident Commander or a Unified Command.
- Update of Water Application Guidance. The Megapack is designed to burn and fully consume itself, and importantly, not propagate to surrounding equipment or spread in any manner beyond the unit experiencing the thermal event. Based on other events and now reinforced by the Elkhorn BESS fire, the application of fire hose water on surrounding Megapacks to mitigate exposure to radiant heat appears to be of limited value. Tesla has already updated their Emergency Response Guide (ERG) (version 2.6) to clarify fire hose water application as discretionary for the specific incident. PG&E is in the process of revising their Pre-Fire Plan (PFP) and Emergency Action Plan (EAP), as well as coordinating with the North County Fire Protection District, on the updates to these plans to reflect the change in focus for water application per the updated Tesla Emergency Response Guide.
- Emergency Action Plan & Pre-Fire Plan Updates and Training. To address an emergency at the Elkhorn BESS, the Emergency Action Plan (EAP) and Pre-Fire Plan (PFP) are critical to addressing the actions taken by all involved. The EAP addresses the safe actions and evacuation of plant and contractor personnel, while the PFP addresses the coordination of all internal and external emergency responders to an emergency event. The multiple lessons learned from this event include the updating of the plans to the most recent Tesla ERG water application guidance, clarification of roles and responsibilities for PG&E First Responders, and training requirements for these roles in order to properly function within the Incident Command System. PG&E is reviewing and updating both the EAP and PFP to reflect these and other points realized during the incident review.
- Periodic Drills and Tabletop Exercises. Incident response requires familiarity with the facility and exercising of plans, i.e., the EAP and PFP, which are already conducted for Elkhorn BESS. These should be continued and as a minimum include regularly scheduled familiarization drills (i.e., walkthrough) for local emergency responders and also consider more rigorous annual Tabletop Exercises that integrate multiple departments and agencies into the scenario. Additionally, all periodic drills and training should capture and process updates to the EAP and PFP, as well as other documentation.
- Critical Operation Power Supply. During the early hours of the fire, the 115 kV breakers were intentionally opened for safety considerations. The de-energizing of these electrical breakers inadvertently shut down the ability to control the movable camera at the Incident Command Building, which was necessary to visually assess the progress of the fire. PG&E has

indicated they are addressing the electrical supply to the CCTV cameras to ensure that they can be remotely adjusted should power be removed to the 115 KV lines.

- Airborne Contaminant Exposure Monitoring. During the fire and when heavy fog settled-in, Unified Command issued road closure and a shelter-in-place orders out of an abundance of caution. Exposure data for implementing and lifting these orders was not readily available to Command. Consider the following steps for conducting real-time airborne contaminant exposure monitoring:
  i. Establish Target Exposure Constituents. For a burning Megapack, involved in a credible worst-case fire event, Tesla with PG&E should clearly identify the targeted exposure gases and related airborne contaminants for measurement purposes. In addition, the applicable thresholds should be established for each targeted exposure. In some limited locations and depending upon the local authorities' directives, the targeted exposure data developed beforehand might be employed in modeling software that could provide further clarity for emergency response decision making.
  ii. Exposure Data. Institutionalize beforehand (to the extent possible) the methods and equipment for measuring exposure data. This should provide Incident Command the necessary data they need to effectively evaluate airborne exposures to the facility and neighboring vicinity during a fire.

V. Summary

Overall, this fire event proceeded in accordance with its fire protection design, and presented no unusual, unexpected, or surprising characteristics, such as an over-pressure event or explosion (see Appendix for the Megapack fire protection approach). The fire involved a single Megapack. The fire proceeded in accordance with its design and consumed itself. It burned as a flaming fire for about 6 hours, and then generated visible smoke and off-gas for another 12 hours. As per the instructions in Tesla's Lithium-Ion Battery Emergency Response Guide (ERG), which were incorporated into the PG&E Pre-Fire Plan, the Megapack was allowed to burn and consume itself while being monitored by first responders at a safe distance.

The order for road closure & shelter-in-place (half-day) had been implemented out of an abundance of caution at the time of the event based on a lack of necessary data. Tesla is working to acquire the data to avert potential future closures and shutdowns. Importantly, subsequent testing indicated that water and airborne samples from this event showed minimal environmental impact.

It is noteworthy that no site personnel, workers, emergency responders, or others (i.e., the public) were injured. Property damage was primarily limited to the loss of a single Megapack out of the 256 units that occupy the site, i.e., less than 0.5% of the facility's battery energy storage capacity. The event had minimal adverse impact on the electrical grid, and had appreciably short facility mission interruption beyond the investigation stage.

APPENDIX: Megapack's Fire Protection Approach

The predominant hazards facing emergency responders during a BESS fire event are fire (heat), explosion (over-pressure), electric shock, and contamination. Fire containment and contamination control are two activities that are relatively predictable during a BESS fire, and not an undue challenge for a well-trained and well-equipped fire service organization (such as the NCFPD). On the other hand, the occurrence of explosion and/or electric shock hazards are less predictable, and thus a greater challenge for firefighter safety.

The Megapack has a fire protection design approach that minimizes the dangers of explosions and/or electric shock. Tesla's ERG recommendation is to fight a Megapack fire defensively. The fire crew should maintain a safe distance and allow the battery to burn itself out. As required, firefighters should utilize hose lines (i.e., water spray) to protect exposures or control the path of smoke, and not apply water onto or into the specific unit on fire.

This is consistent with the firefighting approach used throughout the Elkhorn BESS fire. This defensive approach i.e., not opening the Megapack doors and actively attacking the internal fire, manages the fire and minimizes firefighter exposure to explosion and/or electric shock hazards (Note: Megapack doors are designed to remain closed during a thermal event). Containing the fire and making sure it does not spread, as well as contamination control, are readily achievable goals for modern fire service crews. Managing the fire in this manner allows the primary fuel (the energized batteries) to fully consume themselves. The NCFPD effectively utilized this firefighting approach at the Elkhorn BESS fire, and consequently minimized unnecessary and dangerous risks to firefighters and site personnel.

This managed, defensive fire control approach significantly lowers the exposure to firefighters of an explosion. The approach allows unburned combustible gases and vapors to be consumed before they can accumulate and generate an over-pressure event. In addition, the Megapack utilizes a proprietary sparker system that functions continuously within each unit to eliminate the confined build-up of unburned combustible gases and vapors. All of this is in addition to the over-pressure vent panels on the top of each enclosure. In summary, an in-depth fire safety strategy is inherent with the Megapack design to protect firefighters from an explosion.

From a firefighting standpoint, the dangers to firefighters with a BESS fire are real and significant, with explosions being the predominant concern. There are two recent case study events that involved BESS designs unlike Tesla's Megapack that resulted in firefighter line of duty deaths (LODD) and injuries. An April 2021 fire in a Beijing China power facility resulted in the deaths of two firefighters due to an explosion.[1] Similarly, an April 2019 fire in a Surprise Arizona USA power

[1] Source: CTIF: International Association of Fire and Rescue Services, "Accident analysis of Beijing Jimei Dahongmen 25 MWh DC solar- storage-charging integrated station project", Institute of Energy Storage and Novel Electric Technology, China Electric Power Technology Co. Ltd., Apr 2021, URL: https://www.ctif.org/sites/default/files/2021-05/Accidental%20analysis%20%281%29.pdf, Accessed: 6 Dec 2021.

facility had an explosion that seriously injured four hazmat team firefighters.[2] The Megapacks and the Elkhorn BESS facility utilize a fire protection approach that is advanced well beyond these other case study applications, which greatly minimizes the risk of explosions.

The electric shock hazard is obviously present within an energized electrical grid facility, but it becomes a special problem with stranded electrical energy. Stranded energy is the remaining (often lethal) electrical energy in a battery that cannot be readily dissipated or monitored because of physical damage to the battery (e.g., from fire). This not only presents an electrocution risk to firefighters during final overhaul, but similarly is a significant risk to technical crews involved with final de-commissioning and disposal. The de-commissioning and disposal process in other fire events (not Elkhorn BESS) has shown this process can take months to complete.

The fire protection design approach of the Megapack has inherent advantages over other BESS designs in terms of safety to emergency responders. The Megapack approach minimizes the likelihood of fire spread using compartmentation and separation, eliminates the danger to firefighters of an overpressure event due to design features and a lack of confinement (e.g., outdoor versus indoor), does not rely on active firefighting measures like external hose lines, and minimizes the dangers from stranded electrical energy to those involved with overhaul and de-commissioning with a fire response approach permitting the Megapack to safely burn itself out.

[2] Source: McKinnon M, DeCrane S, Kerber S, "Four Firefighters Injured In Lithium-Ion Battery Energy Storage System Explosion – Arizona", UL Firefighter Safety Research Institute, 2020, URL: https://dx.doi.org/10.54206/102376/TEHS4612, Accessed: 6 Dec 2021.