Accident analysis of Beijing Jimei Dahongmen 25 MWh DC solar-storage-charging integrated station project

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April 2021

1. General information of the project

Jimei Dahongmen 25 MWh DC photovoltaic-storage-charging integrated station project was reported to the Development and Reform Commission (DRC) of Fengtai district of Beijing city in April 2018. This project was developed and operated by Beijing Fuweisi Oil & Gas Co., Ltd. The 1st phase of the project includes a 1.4 MWh roof-based solar photovoltaic energy system, 94 parking lots equipped with 150 KW single highly powerful DC fast charging piles. Among the 25 MWh capacity, 12.5 MWh is used to charge external EV cars (including 4.0 MWh for private vehicles in the south area + 8.5 MWh for public buses in the north area) and 12.5 MWh for indoor electricity supply.

This project was commercialized in March 2019, which was the biggest commercial energy storage station for customers in central Beijing city, the largest scale public charging station, the first MWh-level solar photovoltaic energy storage-charging station, the first user side new energy DC incremental distribution network, the largest demonstration project of solar photovoltaic energy storage-charging. The project layout is shown in Fig. 1.

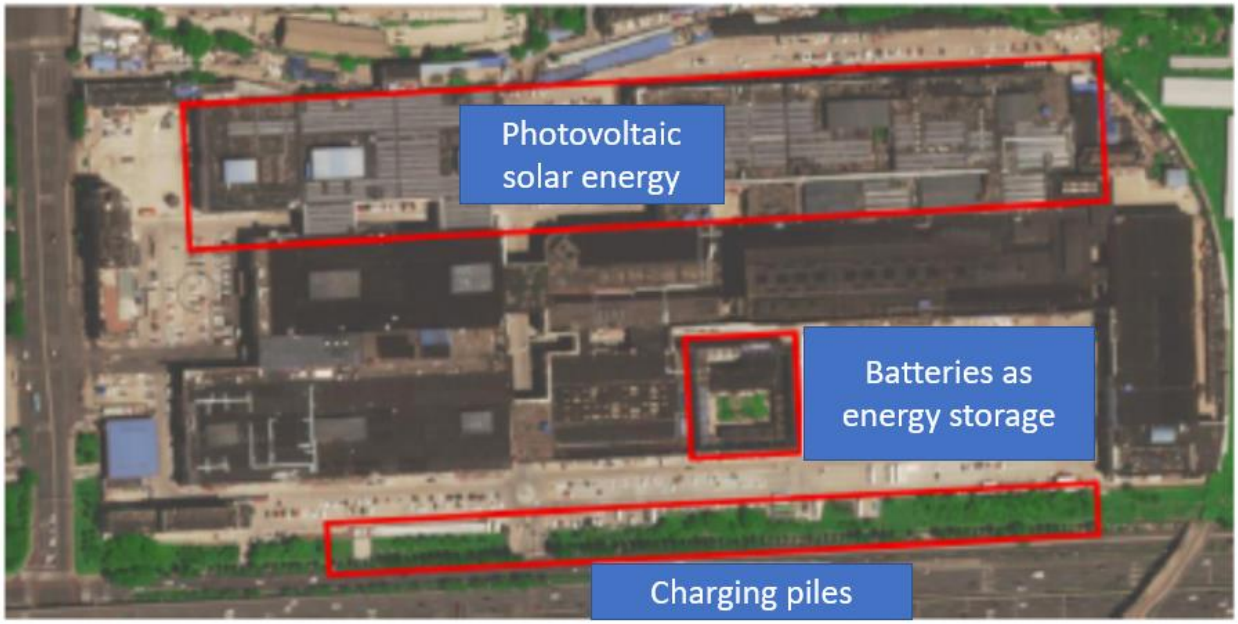

Fig. 1 The layout of the 25 MWh solar-storage-charging project

The batteries are provided by Guoxuan High-Tech Co., Ltd (3.2 V 10.5 Ah lithium iron phosphate square shell). The single cells were connected in parallel firstly and then in series by 225S18P mode (225 single cells connected in series to form a string, then 18 strings were connected in parallel) to construct a battery module with 720 V of voltage and 189 Ah current. The battery cluster was finally made by connect several battery modules in parallel. Details can be found in Fig. 2.

Fig. 2 Battery cluster

Monocrystalline silicon photovoltaic panels were installed on the rooftop idle space of Jimei Furnishing plaza to construct the photovoltaic electricity generation system, as shown in Fig. 3. Charging piles were installed for electric vehicles, see Fig. 4. The solar storage-charging system was made by integrating the sub-systems of photovoltaic electricity generation, AI charging piles and energy storage. For the energy storage system, handheld

firefighting equipment was equipped near the battery clusters for the emergency treatment of early accidents.

Fig. 3 Photovoltaic electricity generation system

Fig. 4 EV charging piles

In the integrated solar energy storage and charging project, the sub-system of battery-based energy storage station largely differs from traditional centralized energy storage system with respect to electrical structures. In traditional EV charging stations, the output current is AC, which must be converted to DC and then charge the electric vehicles. Thus, the AC-DC converts are required. The project considered the feature of battery cascade, which directly generate DC as the output. Therefore, the AC-DC converts are removed. Batteries were connected in series to achieve voltage of 750 V, after multi-stage parallel, to deliver power of 150 kW, current of 250 A and voltage of 750 V for each charging pile. The output KPIs correspond to the highest values of national standards of charging piles. Due to the absence of AC-DC converts, the size of the energy storage sub-system is reduced. However, the requirement of current homogenization of battery clusters and on-off ability of the DC switch became higher.

2. Report of the accident

At 12:17 pm on 16th April 2021, the Fire Command Center of Beijing received a report of the fire accident occurred on the Beijng Jimei Dahongmen power station (located in the south area). 47 fire trucks and 235 fire fighters from 15 local fire brigades were sent to the fire site.

Around 14:15 pm, when the fire fighters were dealing with the fire of the power station in the south area, a sudden explosion occurred in the power station in the north area without a warning, **leading to the death of 2 fire fighters, injury of 1 fire fighter and missing of 1 employee of the power station.**

Fig. 5-7 are not translated. Please read the original report.
https://wemp.app/posts/547dac6a-171c-4389-b735-8951c0e8bcd8

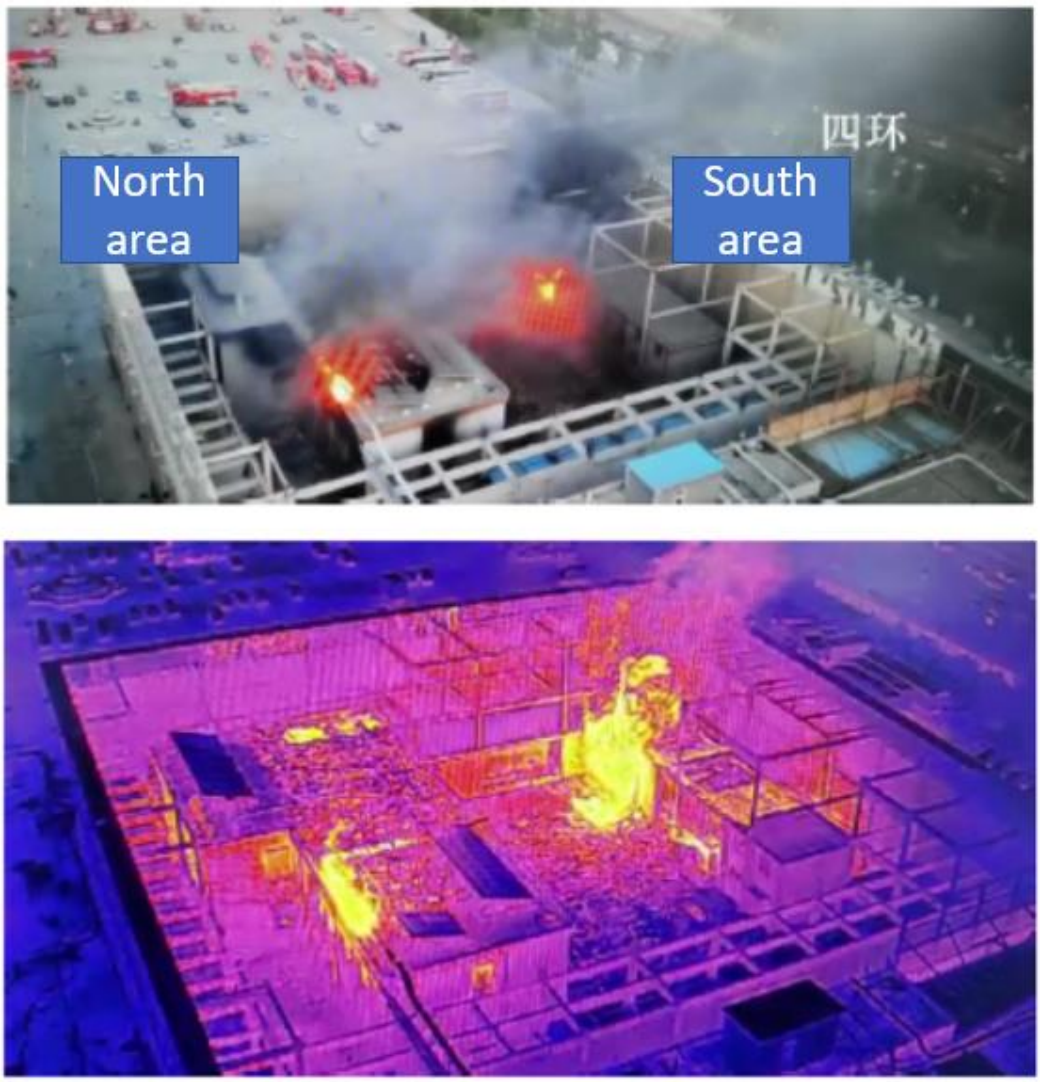

Fig. 8 Aerial photography of the accident scene

It was learnt through preliminary investigation that on-site debugging was undertaken prior to the accident. At 23:40 pm on 16th April 2021, the naked fire was extinguished. However, the cooling-down was still in process. The reasons and property loss were under investigation.

Fig. 9 The power station after fire fighting

3. Analysis of technical reasons

The sudden explosion of the power station in the north area could be explained by the safety accident induction mechanism of lithium batteries, which is the thermal failure of the batteries in the extreme conditions when they were significantly affected by internal and external sources. The safety of battery-based energy storage system is complicated because it involves batteries, battery management systems, cables, system electrical topology, early warning, monitoring and firefighting systems et al. Due to the limitation of accidental information, it is hard to determine the fire accident was initiated by the poor quality of the batteries or the overloading input to the batteries which exceeds the limitation of the batteries. Several possible reasons are proposed as follow.

3.1 The quality of batteries

According to the on-site situation, combustion and explosion occurred on the lithium batteries of the energy storage system, along with heavy smoke. The reason of lithium batteries' combustion and explosion is due to the failure of thermal control inside the batteries, which is triggered by two main reasons: 1. the internal problem of lithium batteries, e. g. the internal short circuit due

to the deficiency of electrode materials, and/or the formation of dendrite lithium during long-term operation. 2. The external reasons, e. g. the irreversible exothermic reaction caused by electric and thermal shock. During the integration of batteries to form the battery clusters, if the selection of batteries' model did not meet the safety requirement, the out-of-control heat is prone to occur due to the low tolerance to the turbulence of temperature during charging-discharging process. In present, the safety test basis of lithium batteries for energy storage purpose is the GB/T36276, the national standard officially started in January 2019. The difference of this national standard, in comparison with the previous standard of lithium batteries as vehicle's power source, is the new technical requirement of heat management and the associated safety performance. Whether the selected batteries in the accidental battery clusters meet the GB/T36276 is unknown. If they did not meet the requirement of GB/T36276, a safety risk is foreseen.

3.2 Electrical topology of energy storage

The electrical topology of the project is DC distribution network structure. The battery cluster was connected to the high-power charging piles and photovoltaic system through the DC/DC converts based on a shared DC bus. The safety risk of this type of electrical topology are:

(1) When the performance of various battery clusters is nonuniform, a circulation of current can be formed during operation. When the circulated current is large, overloading occurs on a single battery cluster, accelerating the aging and degradation of battery clusters.

(2) When short circuit occurs on the DC bus, the short circuit current moves to battery clusters through the DC bus. This instantaneous short-circuit high current may lead to a significant temperature increase within the batteries, leading to a fire as a consequence.

(3) Due to the higher insulation requirements for DC bus, the deficiency of insulation materials potentially causes an arc spark. Since DC current has no zero-crossing point, the arc spark is hard to be extinguished.

Therefore, it is easier for the high temperature arc spark to ignite the batteries and cables.

(4) DC switches are more complicated and the arc spark within the DC switches is harder to be extinguished than that of the AC switches. The switch off time of DC switches is longer and the DC switches are more expensive. In some projects, expensive DC switches were occasionally replaced by cheap AC switches. When AC switches were used in DC systems, these AC switches may not be switched off in case of overload accident, leading to a safety risk.

(5) The lack of adequate electrical isolation measures for power electronic equipment in DC distribution. If the grounding work in the DC power distribution system is not properly handled, electromagnetic circulation problems can easily cause leakage current when the system is running. The accumulated heat due to the leakage current in battery cabinets, cables et al. may cause local high temperatures, leading to potential fire of the batteries as a safety risk.

(6) View from the scene, the fire accident occurred in the south area first. The sudden explosion in the north area happened without warning while fire fighters dealing with the accident in the south area. In this situation, the reason maybe the shared DC bus in the north and south areas. When an accident occurred in the south area, the DC bus in the south area is short-circulated. However, because the DC protection system failed to detect the short circulate current, the DC protection system did not take an action. Thus, the batteries in the north area were over-discharged instantaneously and the current increased, causing the accident.

3.3 Battery management system

In addition to battery cells, battery energy storage systems also include BMS, PCS, transformers and related relay protection equipment, communication equipment and a series of primary and secondary equipment. The equipment may directly or indirectly cause safety problems in the energy

storage system due to quality defects, irregular installation and commissioning processes, unreasonable settings, and inadequate insulation. On 7th March 2017, a fire accident occurred in the lithium battery energy storage system of a power station in Shanxi province, China. According to the investigation report, it is determined that the cause of the fire accident of the energy storage system is the excessive voltage and current caused by the surge effect during the system recovery and startup process, and it is not effectively protected by the BMS system. The battery management system may have a long data collection cycle and an unreasonable threshold setting. The charging and discharging process exacerbates the risk of battery out of control.

3.4 Arrangement of cables and wires

Judging from the public information, the cables of this project were laid by pipe bridges, which were close to the safety distance of the battery cabinet. If the above circuit is short-circulated, the cable will burn or explode, which will easily cause a chain reaction, causing the battery to catch fire or explosion.

The wiring harness in the battery module is also the source of the accident. If all the wiring harnesses are not fireproofed, or the collection wiring harness and the communication wiring harness are not clearly distinguished, it is easy to cause interference between the wiring harnesses and cause inaccurate battery management system information. When an accident occurs, if it is not handled in time, the wiring harness is not fireproof, and it is easy to become a flammable source.

3.5 Power station fire protection design

After the lithium-ion battery fails thermally, on the one hand, it will have a strong thermal shock on the surrounding batteries. On the other hand, the thermal out of control of the battery will generate a large amount of alkane combustible gas. Under the effects of external electrical shock caused by external load short-circuit, thermal shock after battery thermal failure, etc., if

the energy storage system lacks effective protective measures, it may cause the expansion of battery accidents. If the energy storage device is arranged indoors, when the flammable gas reaches a certain concentration, it will explode in case of a naked fire, and more serious situation is the chain explosion accident.

According to the media description, the project has two substations, one main and one attached. The grid-connected end passed through the cable after the DC bus on the low voltage side. When short circulation occurred, fire fighters have already been on-site. Because there is no isolation of the battery energy storage system, explosion occurred just when fire fighters arrived (at 13:30 pm it is the discharging time). It is inferred from this that the fire protection design of the power station is insufficient. The fire protection design on site has no firewall design, lack of isolation and energy absorption facilities, and does not play an effective protective role in the event of an explosion of the energy storage batteries.

3.6 Fire monitoring, alarming and extinguishing system of power station and fire water

According to the site situation, an explosion occurred in the north area. According to this phenomenon, it may be due to the high temperature generated by the fire in the south area. The battery pressure relief valve of the energy storage system in the north area was opened to release the flammable gas generated by the decomposition of the electrolyte, leading to a deflagration. There may be a lack of flammable gas detection devices or failure of the detection devices, failing to effectively detect flammable gases, and failing to make timely warnings, resulting in an explosion. The large fire spread of the energy storage power station indicates that the on-site firefighting system failed to control the fire in the first time, and the hand-held fire extinguishing device installed on the site cannot functionate, which does not meet the fire extinguishing needs of the lithium-ion battery energy storage power stations.

Judging from the accident pictures, when firefighters used firefighting water to extinguish the fire of the energy storage system in the south area, an explosion suddenly occurred in the north area. Due to the close distance between the south and north areas, the firefighting water may touch the energy storage system in the north area when spraying the south area. Since the energy storage system is a high voltage charged body, water spraying may cause a short circuit of the charged body and the cables and induce fire or extended electrical accident. Therefore, in the early stage of the energy storage system fire, when a large number of energy storage batteries have not been affected, the use of water as fire extinguishing medium still requires careful consideration.

3.7 Meteorological environmental factors

It can be seen from the investigation and analysis repot on fire accidents of energy storage power stations in South Korea that environmental factors are the possible causes of fires in energy storage systems. On April 15th, Beijing issued a yellow warning for gale, bule warning for sand dust, and orange warning for forest fires. The meteorological environment of strong wind and sand dust may cause dust accumulation in the energy storage system. On the one hand, it is not conducive to the heat dissipation of the energy storage system and increase the operating temperature of the system. On the other hand, the presence of sand and dust will adversely affect the insulation of the system. Insulation failure can easily cause electrical breakdown of electrical equipment and local high temperature, which will induce thermal failure of energy storage batteries.

3.8 Personnel on-site operation and management system

According to media reports, when the energy storage power station accident occurred, there were workers on site to debug the energy storage system. The energy storage system is a high voltage, high energy live system. There are many cables and wires at the construction site and the commissioning site. If the operation is incorrect or the site is not handled properly, safety problems are prone to occur. From the battery body, integration, engineering

design, construction, operation and maintenance, et al., there are currently relevant standards. If they are not implemented in accordance with the standards, problems such as irregular field operations, lack of supervision, and insufficient understanding of operators will occur, which may lead to serious safety consequences.

4. Suggestions of future work

(1) To strengthen the safe operation management and enhance the technical supervision system of energy storage power station in operation. Clarify management responsibilities and responsible entities. In view of the hidden dangers of different types of energy storage accidents, designate failure emergency plans and fire protection measures to ensure the safety of personnel and property.

(2) To strengthen the application of energy storage technology standards, build a quality management system for energy storage construction, operation and maintenance, implement relevant standard requirements into all aspects of energy storage technology supervision, and ensure the safety and reliability of energy storage equipment connected to the grid.

(3) To accelerate the construction of failure and fire simulation platforms of large-capacity energy storage systems, carry out research on the fire evolution mechanism and preventive control of energy storage systems, build fire hazard level and protection evaluation system of the energy storage systems, verify and improve the adaptation of the energy storage safety system to different environment.

(4) To strengthen safety technology research on energy storage, study energy storage system safety technology in their life cycle application, study energy storage system safety status online perception and diagnosis technology, study energy storage power station safety early warning, flame retardant, heat insulation, fire fighting technology, etc. Take practical and effective measures to accelerate the popularization and application of new technological achievements.

Location of Beijing Jimei Furnishings Dahongmen Charging Station