IFC 2018/ NFPA 855 fire codes –

Lithium battery module in a server rack

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1 Introduction

The International Fire Code states that its purpose "is to establish the minimum requirements consistent with nationally recognized good practice for providing a reasonable level of life safety and property protection from the hazards of fire, explosion or dangerous conditions in new and existing buildings, structures and premises, and to provide a reasonable level of safety to firefighters and emergency responders during emergency operations."

IFC (International Fire Code) has issued a revision **IFC 2018** to address safety requirements for ESS (Energy Storage Systems) that can be used in buildings and facilities. Chapter 12 in IFC 2018 includes the installation, operation, and maintenance of a wide range of energy systems, including photovoltaic systems, fuel cell energy systems, battery storage systems, and capacitor energy systems. National Fire Protection Association (NFPA) has also revised its standards to adopt similar requirements in NFPA 855 to maintain consistency with IFC2018.

This white paper addresses the following;

- Key requirements of IFC2018 and NFPA855
- Server rack architecture containing the BBU (Battery Backup Unit)
- Fire hazard mitigation systems in the existing data center
- Industry opinions

Any AHJ (Authority Having Jurisdiction) can take this into consideration as they decide whether to adopt the NFPA 855 or IFC2018 codes. The BBUs are included in most compute rack systems to provide uninterrupted power for a short duration if the main power fails. The objective of this white paper is to clarify technical details of the in-rack BBU and its purpose, to differentiate it from stationary energy storage systems defined within the scope of IFC2018 and NFPA855 codes.

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2 New requirements in IFC2018/NFPA855

IFC2108 Section 1206 and NFPA855 Chapter 1 define the requirements thresholds for different capacities of battery technologies. When a battery system exceeds the threshold value in the table, the facility must meet new provisions – such as those for MAQ (Maximum Allowable Quantities), maximum array size, physical separation, hazard mitigation, installation and operation, fire detection systems, and energy management systems.

Battery storage system threshold quantities (Reference: IFC2108, Table 1206.2)

Battery technology	Capacity(a)
Flow batteries (b)	20kWh
Lead acid, all types	70kWh
Lithium, all types	20kWh
Nickel cadmium (Ni-Cd)	70kWh
Sodium, all types	20kWh (c)
Other battery technology	10kWh

For SI: 1 kilowatt hour = 3.6 megajoules
a: For batteries rated in amp-hours, kWh shall equal rated voltage times amp-hour rating divided by 1000
b. Shall include vanadium, zinc-bromine, polysulfide-bromide, and other flowing electrolyte-type technologies
c. 70kWh for sodium-ion technologies

Stationary batteries locations
IFC 2018 imposes a restriction prohibiting ESS (except for lead-acid and nickel-cadmium batteries) installation more than 75 feet above the lowest level of fire department vehicle access. Additionally, battery storage systems cannot be placed more than 30 feet below the finished floor of the lowest level of exit discharge.

NFPA-855 also requires that ESS (except for lead-acid and nickel-cadmium batteries) be installed only on floors (except a noncombustible rooftop exceeding 75 ft) that can be accessed by external fire department laddering capabilities, unless a higher location is approved by the AHJ.

While each AHJ retains the right to determine whether and with what modifications to adopt the IFC and NFPA requirements within their fire codes, certain restrictions could have a major impact -- especially if a battery storage system needs to be installed in a multistory data center building.

Separation criteria for stationary battery arrays
IFC Section 1206 requires that battery storage systems shall be segregated into arrays not exceeding 50kWh each (250kWh in case it is listed), and that each array shall be spaced not less than 3 feet from other arrays in the room.

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Maximum Allowable Quantities (MAQ)

MAQ (Maximum Allowable Quantities) for different types of batteries are defined in IFC2018 Section 1206. If the facility contains battery systems exceeding the maximum allowable quantities listed in the following table, it can be classified as a high-hazard occupancy group H2 and must comply with increased physical and operational safety criteria under specified failure conditions. Detailed criteria for Group H2 are described in the occupancy sections of the IFC/IBC or NFPA-1.

Maximum Allowable Battery Quantities (Reference: IFC2108, table 1206.2.9)

Battery technology	Maximum Allowable Quantities(a)	Group H Occupancy
Flow batteries (b)	600 kWh	Group H-2
Lead acid, all types	Unlimited	Not Applicable
Lithium, all types	600 kWh	Group H-2
Nickel cadmium (Ni-Cd)	Unlimited	Not Applicable
Sodium, all types	600 kWh	Group H-2
Other battery technology	200 kWh	Group H-2 (c)

For SI: 1 kilowatt hour = 3.6 megajoules

a: For batteries rated in amp-hours, kWh shall equal rated voltage times amp-hour rating divided by 1,000

b. Shall include vanadium, zinc-bromine, polysulfide-bromide, and other flowing electrolyte-type technologies

c. Shall be a Group H-4 occupancy if the fire code official determines that a fire or thermal runaway involving the battery technology does not represent a significant fire hazard.

Occupancy H-2

- Thermal runaway condition
- Failure of any energy management system
- Failure of any required ventilation system
- Voltage surges on the primary electric supply
- Short circuits on the load side of the stationary battery storage system
- Failure of the smoke detection, fire suppression, and gas detection system. Spill neutralization not being provided or failure of the secondary containment system

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Energy management system
An approved energy management system shall be provided for battery technologies, other than lead-acid and nickel cadmium, for monitoring and balancing cell voltages, current, and temperatures. This system shall be equipped with a suitable alarm system that shall be activated when it detects any abnormal operating condition, such as a short circuit, or over- and under-voltage conditions.

Fire extinguishing, smoke and gas detections
The facility containing the stationary battery storage battery system shall be equipped with an approved automatic sprinkler and smoke detection system. The facility must be also protected by a gas detection system that is designed to activate where the level of flammable gas exceeds 25% of the lower flammable limit. And the level of toxic or highly toxic gases shall not exceed one half of the IDLH (Immediately Dangerous to Life or Health) level in the building. Activation of the gas detection system shall initiate audible and visible alarms, de-energizing of the battery charger, and activation of the mechanical ventilation system.

Ventilation
The facility containing the stationary battery storage system shall be equipped with the ventilation system that is designed to limit the maximum concentration of flammable gas to 25% of the lower flammability limit, or 1% of the total volume of the room for hydrogen. Continuous ventilation shall be at a rate of not less than 1 cfm per square foot of floor area, but not less than 150cfm.

Large-scale fire tests
NFPA855 requires that large-scale fire tests shall be performed on a representative energy storage system sample in accordance with UL9540A standard. This is to evaluate whether the fire will spread to adjacent energy storage systems. AHJ will use the data to determine the clearance and installation requirements.

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3 Data center power backup systems

Data center description and rack layout
The electrical distribution for a data center that operates with AC voltage accommodates High/Medium Voltage distribution from a utility to a Low Voltage that can be used at an IT rack. The data center electrical design also anticipates backup power provision for racks during any interruptions in the utility's service.

Several design approaches can be considered. A common approach for Low Voltage and Backup systems is an Uninterrupted Power Supply (UPS) that consists of four major functional components:

Converter - To change the voltage level between the input (utility) and the output.
Batteries - To provide uninterrupted DC power in case of a utility outage.
Inverter - To convert DC battery voltage and current to AC.
Switches - To accommodate switching between the working modes, whether AC or DC or Bypass.

A **standby generator** may be used to provide backup power for extended periods. In case of a utility outage, the UPS would use internal batteries to sustain service during switching between utility input and a generator. Alternatively, if the UPS batteries have sufficient capacity in a particular application, they may sustain the system for the duration of the outage.

The output of the UPS is converted to DC voltage serving the IT gear in the rack through an additional Power Supply Unit (PSU). This is a viable design option, but it is complex and it may impact the efficiency, reliability, and cost of the system.

A different approach in data center electrical designs eliminates the use of a UPS and accommodates the backup power required for transitions from one source (utility) to another (generator) through a simpler power architecture within the server rack itself. Within the rack, the Low Voltage utility input is converted into DC through a PSU, and a Battery Backup Unit (BBU) effects the transition between the sources to the rack in case of an outage.

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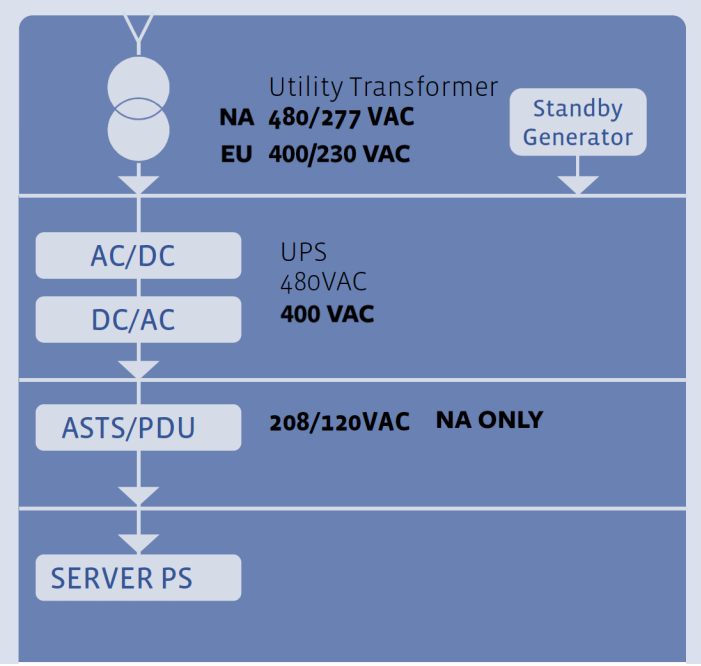

Figure 1: Standard Data Center Electrical design

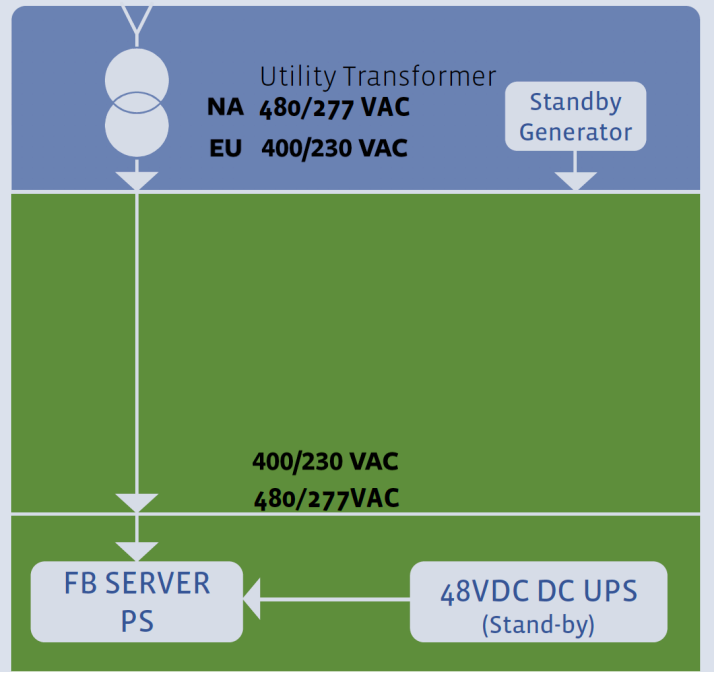

Figure 2: FB Data Center Electrical Design

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In-rack battery architecture (high level)

The Open Rack V2 power architecture disaggregates the power distribution of the rack from the server tray. Two power stations are used to provide both AC/DC functionality and allowance for transition times in the event of outages, by means of batteries. The power stations are not electrically connected, and their DC outputs are distributed via busbars in the rack.

Figure 1: Server rack with PSU (including three BBUs). In a data center, the empty slots are occupied by servers and networking switches

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Each power shelf consists of three PSUs and three BBUs. The input to the power supplies is Line to Neutral, with each representing a phase in a 3-phase input to the rack delivered by the data center electrical distribution. While the power supplies share their outputs from the shelves to the busbar within the rack, the BBUs do not. Each BBU is electrically connected only to its corresponding PSU, and charge/discharge happens through that power supply only. Thus, the BBU has no connection to the data center electrical distribution system, or to anything outside the rack.

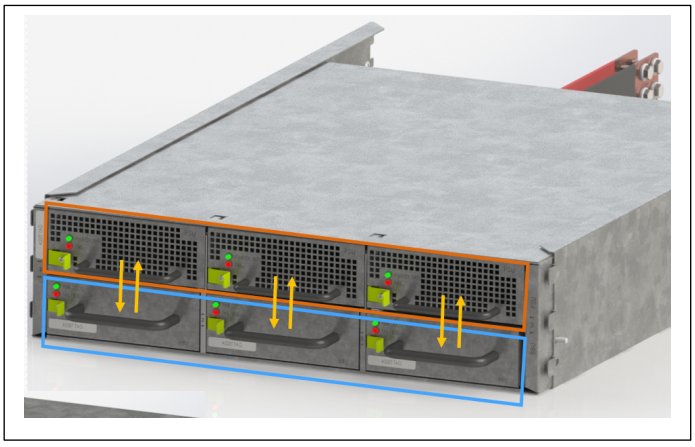

Figure 2: Power shelf-containing three PSUs (red boxes) and three BBUs (blue boxes)

Figure 3: BBU module removed from power shelf

How does it work? Why is it needed?

Similar to what is described above, the BBU is needed to maintain the load during transition between power sources. During an outage, the data center electrical distribution transfers to a generator for the input to the rack, which can be counted as the first transition. When the utility service returns and is stable, the distribution transfers from the generator to the utility -- the second transition. In cases where the generator is not present or not turned on, the BBU may

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maintain the load commensurate with its available capacity or its design restrictions.

Each BBU utilizes the energy and power density of **lithium-ion** batteries in a pack, along with a Battery Management System (BMS) that provides safety, control, and monitoring capabilities. In addition to the pack design, the battery cell itself provides internal safety. Moreover, the PSUs enforce additional layers of safety in utilization of the BBU, whether in discharge or charge scenarios.

For example, when the input to the rack is lost in an outage, the PSU detects the AC loss and engages an algorithm for switching to the BBU. Once engaged, the BBU is discharged into its corresponding power supply and the PSU performs adequate voltage level changes to the load. In ORv2 design, the same DC/DC converter (after rectification) is fed by the DC input from the BBUs.

What other in-rack approaches can be designed?
Open Rack V2 design leverages its PSUs to utilize and regulate the input and output of the BBUs. In alternate designs, the BBU(s) may be independent: The rectification of the AC input to the rack would be achieved through the PSUs in a shelf, and the BBUs would reside in their own shelf, connected to the rack busbar, either regulated or unregulated. This approach follows the same premise as ORv2, where the BBUs have no electrical connections outside of the rack.

How is this differentiated from a stationary power system, such as UPS ?
As described above, the major difference between this in-rack power architecture and one utilizing a UPS is the connection to the data center. With an in-rack approach, the batteries only electrically interface within the rack. This results in a more localized electrical design: Not a permanent electrical installation, but rather one that gives simple flexibility to do swaps or repairs. In addition, compared to the UPS approach the failure domain of the BBUs is greatly reduced. The rating of the battery backup is proportionate to the rack's rating, not to the rating of the data center or the data halls.

Several tests are performed during the design phase to verify that the failure domain of a BBU is limited to the unit itself. One of the most destructive of such tests uses a fully charged BBU, and identifies the most problematic thermal location for the battery pack with respect to thermal propagation. A short circuit is induced in the cell through a "nail penetration test." This destructive test mimics the highly unlikely occurrence of thermal runaway and its implications inside the rack. As a result of the nail penetration, the cell triggers its protection mechanisms, vents its internal pressure from the gas generated, all while its temperature increases dramatically from ambient levels. The objective of the test is to assess the propagation of failure from one cell to another, and even beyond the unit. Because of the attention given to the mechanical and electrical details of the V2 BBU design, such tests have shown conclusively that the fault is not propagated to neighboring cells, and all effects of the failure are encapsulated within the unit.

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4 Fire hazard mitigation systems in the data center

Data-hall fire protection system
Data-hall server racks are equipped with a double-interlock Preaction Sprinkler fire-protection system. Automatic sprinklers are attached to piping fitted with a Preaction valve. The activation of a smoke detection system located in the same area as the sprinkler will trigger a pre-determined investigation timer and bring the fire alarm system to a pre-alarm stage. A signal will then be sent to the Preaction sprinkler control panel to release its solenoid valve. The activation of any sprinkler head in the fire zone will cause a drop in piping system pressure, release the Preaction valve, and allow water to be charged into the system.

Valve Regulated Lead Acid (VRLA) UPS battery room fire protection system
VRLA UPS Battery rooms are equipped with the Double-Interlock Preaction Sprinkler System.

Very Early Smoke Detection Apparatus (VESDA) System
This detection system enables very early warning of fire by drawing air samples through an air-sampling pipe network that extends through data halls and core network rooms. The VESDA system has four stages (Alert, Action, Fire 1, and Fire 2). When the Fire stage is reached, the smoke detection system will activate the sprinkler-system charging mechanism. This system is designed in accordance with NFPA-72, NFPA-75, NFPA-76, SS CP10, Singapore Fire Code SCDF-2018, BS 5839, BS 6266, and Manufacturer guidelines.

Fire alarm system
The data center is equipped with a fully addressable fire alarm and emergency communication system including but not limited to: Fire alarm control panels, fire alarm graphic station, remote control panels, remote annunciators, spot-type detector, duct probe detector, aspirating smoke detectors, heat detectors, manual pull stations, alarm initiating devices, and notification appliances. The systems are designed in accordance with the following standards: NFPA-3, NFPA-4, NFPA-72, NFPA-75, NFPA-76, SS CP10, Singapore Fire Code SCDF 2018, BS 5839, and BS 6266.

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5 Concerns and suggestions

We agree that Energy Storage Systems must be regulated to mitigate fire safety hazards, and we applaud the steps that both ICC and NFPA are taking in that direction. However, it must be noted that the new codes are causing confusion, due to a lack of guidance. A Stationary Energy Storage System is defined as a "rechargeable energy storage system consisting of electrochemical storage batteries, battery chargers, controls and associated electrical equipment designed to provide electrical power to a building or facility. The system is typically used to provide standby or an uninterruptible power supply, load shedding, load sharing or similar capabilities."

A major concern is that some AHJs may regulate the in-rack BBU as they would stationary storage systems, due to an overly broad interpretation of the Energy Storage System definition. Such strictures would impose a major burden on the data center industry, in that buildings and fire protection systems would need to be significantly reworked to comply with the additional requirements.

A BBU using lithium-ion battery cells is integrated into a server rack system as described in Section 3. Because a data center building contains thousands of such racks, were each server rack to be deemed a "stationary storage system" it could vastly exceed MAQ criteria. In that case, the facility would need to provide AHJ with documents showing compliance with requirements described in Section 2, together with large-scale fire test data that AHJ would use to determine the fire hazard and evaluate the functionality of safeguards.

While the BBUs may provide uninterruptable power to specific equipment, they do not provide power to a building or facility as defined in IFC 2018. Each BBU provides power only to servers and other electronic equipment installed on the same rack. The BBUs within the rack can be moved to another location simply by unplugging and re-plugging their connections. Given this portability, a BBU should be regarded as a component of the server rack – with a functionality very different from that of a stationary energy storage system. The BBU as a component is typically certified to UL62133 and UL1973 standards, and the power shelf containing BBUs is additionally certified to IEC62368-1 standard including Annex M for battery safety by NRTL (Nationally Recognized Test Laboratory).

Thus, a BBU in a server rack should be viewed differently from a standalone stationary battery system, and exempt from the requirements for stationary storage battery systems. The regulations in IFC2018 Section 1206 and NFPA855 should not be extended to server-rack BBUs.

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6 Glossary

AHJ: Authority Having Jurisdiction
BBU: Battery Backup Unit. A component of a server rack system
BMS: Battery Management System
ESS: Energy Storage System
ICC: The International Code Council, developing standards related to building construction.
IFC: International Fire Code
MAQ: Maximum Allowable Quantities
NFPA: The National Fire Protection Association (NFPA,) a global self-funded nonprofit organization
NRTL: Nationally Recognized Test Laboratories
PSU: Power Supply Unit installed in the server rack system
VESDA: Very Early Smoke Detection Apparatus System
VRLA: Valve Regulated Liquid Acid UPS system

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7 References

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UL1973: Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications, Ed.2, 2018.
UL9540A: Testing fire safety hazards associated with propagating thermal runaway within battery systems, 2019.

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8 About Open Compute Foundation

The Open Compute Project Foundation is a 501(c)(6) organization which was founded in 2011 by Facebook, Intel, and Rackspace. Our mission is to apply the benefits of open source to hardware and rapidly increase the pace of innovation in, near, and around the data center and beyond. The Open Compute Project (OCP) is a collaborative community focused on redesigning hardware technology to efficiently support the growing demands on compute infrastructure. For more information about OCP, please visit us at http://www.opencompute.org

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