All What You Need to Know About Fast Charging

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Introduction

Fast charging of industrial batteries is poised to become a main stream charging technology due to the operational savings and the increased productivity and safety that this technology offers. Users are realizing the benefits of fast charging as fast charge systems are already buzzing at manufacturing plants and distributions centers all around the US.

History

Fast charging is by no means a new technology. The concept of fast charging was first introduced in the 1970s with focus on NiCad batteries used in handheld applications. By early 1990s, fast charging was expanded to electric vehicles (on-road EVs) as a way to reduce charge time and make highway travel with an EV a reality. With the demise of the EV market potential by mid to late 1990s, the fast charging concept was further extended to industrial forklift truck batteries. Although many users and battery OEMs alike were quite skeptical of fast charging, extended field trials have demonstrated the viability of this technology and the durability of industrial batteries in such applications.

Definitions (Conventional / Opportunity / Fast Charging)

Presently, there are three charging regimen that can be employed to charge a battery, namely conventional, opportunity, and fast charging.

Conventional Charging: With conventional charging, a battery is charged at a rate of 16-18A/100Ahrs and it takes and average of 8-10 hours to fully charge the battery. Note that conventional chargers always charge the battery to a 100% state of charge (SOC) on a daily basis, a process that involves considerable gassing to bring the battery to name plate specific gravity. This entails placing the chargers in centralized charging areas with to maintain hydrogen concentrations well below OSHA limits.

Conventional charging entails that the battery is charged over an 8-10 hour period, rests for another 8 hours, and is used over an 8-hour shift. As such, conventional charging is ideal for one shift applications where no battery charging would be required. In multi-shift operations (two or three shifts) one needs more than one battery per truck which requires battery changing in between shifts or within a shift for extended shift operations.

Opportunity Charging: Opportunity charging involves charging the battery at ~25A /100 Ahrs charge rates at every opportunity possible (e.g. lunch breaks and in between shift breaks). Due to the frequent charging and in order to limit battery gas generation, opportunity chargers are normally set to charge a battery up to 80%-85% SOC throughout the day and back to 100% only once a day (e.g. during night hours). Opportunity charging offers is a good choice for extended shift operations where battery changing can be eliminated. In addition, opportunity charging extends the run time of aging batteries and recoups the lost capacity that comes with age (note the battery's end of life criteria is when the battery capacity reaches 80% of its new value).

Fast Charging: In contrast to conventional charging, fast charging involves charging the battery at rates of 40-60A/100Ahrs (3-4 times conventional charge rates) at every opportunity possible. This includes breaks within and in-between shifts as well as lunch breaks. As such, a single battery per truck can be used thus eliminating the need for additional batteries as well as eliminating all battery changing between shifts.

With fast charging, the batteries are only charged to 80%-85% SOC on a daily basis thus eliminating any unnecessary gassing. Note that the battery is required to be finish charged and equalized (100% SOC) at least once a week, which is normally done on weekends.

Benefits of Fast Charging

When conventional charging is employed in two and three shift applications, and since the required battery to truck ratio is 2-3 with a typical battery usage of 8-10 hours over a 24 hour period, the battery utilization (asset utilization) is 33% on average, a poor ratio for efficient asset use.

With fast charging, and due to the higher charging rate and the more frequent charging throughout the day, a single battery per truck is needed. This eliminates the need for additional batteries as well as improves truck driver productivity as it eliminates the time wasted in changing batteries in two and three shift applications. In addition, and since a single battery is needed, the battery utilization factor jumps to a full 100% (full utilization of the assets under roof).

One of the major benefits of fast charging is the productivity improvement of truck drivers due to the elimination of battery changing. Note that with conventional charging, it takes anywhere between 20-30+ minutes to change a battery within a shift or at the end of the shift. This includes the time it takes to get to the battery room which may be at the other end of the plant. Although this is paid time to the truck driver, the battery change time is rather unproductive. Since fast charging utilizes the scheduled down times of the driver / truck (lunch breaks / morning and afternoon breaks), there is no more wasted time.

Another benefit of fast charging is the elimination of the need for battery room attendants. Note that with conventional charging and if the number of trucks / batteries is large, a battery room attendant is assigned to change batteries at the end of shifts and ensure proper charging of batteries. Since with fast charging only one battery per truck is needed and since the battery is charged on the truck, no battery room is needed and hence no attendant needs to be assigned for this task.

Another side benefit of fast charging is the improvement in workers' safety due to the elimination of dropped batteries or acid spills that mat result from removing batteries in and out of forklift trucks as well as the reduction of truck accidents that may occur near battery rooms during shift changes.

Fast Charging for New Manufacturing & Distribution Facilities

New manufacturing and distribution facilities are the sweet spots for fast charging applications. This is due to the fact that many costs can be eliminated up front when deciding on fast charging versus conventional charging. These cost savings include:

- Eliminating battery rooms and associated construction costs as well as ventilation systems that are needed for conventional charging applications
- Recovering manufacturing space that would otherwise be given up for battery rooms
- Eliminating battery changing equipment
- Eliminating excess battery inventory under roof since one battery per truck is needed with fast charging and the batteries always remain on the truck
- Improving worker's safety or acid spills due to changing batteries in and out of the forklifts

Although fast charging entails higher initial investments in many applications, interestingly enough this may not be the case in new manufacturing and distribution facilities as the above cost savings almost may more than offset such higher initial investments. Even if the initial investments are higher, the payback period is very short (less than 1 year in most cases).

ROI

Well, it all boils down to an ROI that meets the finance manager's requirements. The good news is that the ROI and NPV of fast charging in two and three shift operation well exceeds the return requirements of the most aggressive finance managers. Although the cost of fast charging equipment is quite higher than that of conventional chargers, significant operational savings as well as initial investment savings can be realized. Lets consider the case of a manufacturing facility planning to acquire (or upgrade) a forklift truck fleet of 50 trucks. With conventional charging, and assuming a ratio of 2.2 batteries per truck, 120 batteries would need to be purchased versus only 50 batteries with fast charging. In addition, with conventional charging, battery extraction and changing equipment will also be needed to change batteries between shifts. A simple run through the initial investment costs as well as the operational savings of conventional versus fast charging is shown below:

Capital Costs

	Conventional		Fast	
	No. of Units	**Cost**	**No. of Units**	**Cost**
Batteries	120 @ 4000	$480,000	50 @ 5000	$250,000
Chargers	50 @ $2000	$100,000	50 $11,000	$550,000
Changing Equipment		$50,000		$0
Total		**$630,000**		**$800,000**

Note the additional cost of the fast charge battery is due to the extra finishing as fast charge battery requires as well as added accessories recommended with fast charge batteries which include a single point watering system and a battery monitoring unit.

Additional Initial Investment = **$170,000**

Annual Savings

Saving	**Detail**	**Calculations**	**Annual Savings**
Productivity → No battery changing	• **2 shifts per day** • **2 battery changes / truck / day → Total 100 changes for 50 trucks** • **20 min. / battery change (0.33 hrs)** • **$25 / hour labor rate (loaded)** • **5 days / week → 250 days / yr**	**100 x 0.33 x $25 x 250**	**$206,250**
No Battery Room Attendant → Moved to another job	• **1 attendant / shift (2 / day)** • **8 hours / shift** • **$25 / hour labor rate (loaded)**	**2 x 8 x $25 x 250**	**$100,000**
Floor Space Savings → No battery room	**4000 Sq Ft @ $25 / Sq Ft**	**4000 x $25**	**$100,000**
Additional Batteries Needed	**Battery life is 3 years in fast charging vs. 5 in conventional (need new batteries by year 3)**	**3/5 x 50 x $5000 /3**	**($50,000)**
		Total Annual Savings	**$356,250**

ROI = 0.47 Years

Additional savings can be realized from the improved efficiency of fast chargers versus conventional chargers as well as improvement in worker safety as they do not have to move the batteries in and out of the truck on a regular basis.

Fast Charging Requirements

Fast charging entails various requirements for the battery, truck, chargers, electrical infrastructure, and charger placement.

- ***Battery Requirements*:** The basic cell construction of a fast charge battery is that same as that of a conventional battery. What differentiates a fast charge battery from its conventional counter part is the final construction of the battery tray as well as the recommended accessories that are installed on the battery. As for construction, fast charge batteries are commonly equipped with dual intercell connectors, and dual cables with dual connectors for application requiring charging amps in excess of 300A. In some instances, the batteries are also equipped with copper post inserts which tend to reduce the contact resistance of the post. Finally, some fast charge batteries are built with vents in between the battery cells to allow for improved cooling (will be discussed later).

In addition to construction requirements, fast charge batteries need to be equipped with a number of accessories, which include a single point watering system with water level indicator, an electrolyte temperature sensor (thermistor), and an optional battery monitoring unit. Since temperature data (or battery monitor data) need to be fed back to the charger, connectors with auxiliary contact pins are required. Although SBX connectors incorporate auxiliary contact pins, Euro type connectors have more durable auxiliary contact pins that are molded within the connector housing.

- ***Truck Requirements*:** From a truck standpoint, there are minimal requirements to allow a truck to be operated in a fast charge application. This includes permanent mounting of connectors on the truck especially when dual battery cables and connectors are involved. If a single battery cable / connector is used, then there are no changes required on the truck side. Other optional accessories that can be installed on the truck are fans to cool down the battery as well as reduce heat rise under the hood thus isolating drivers' seats from battery heat. Fans also can also improve battery performance due to the lower battery operating temperature resulting from active cooling.

  Another requirement, which is normally overlooked, is the need for vents within the battery compartment. Many trucks have conventional designs where the battery is fully enclosed within the battery compartment. This can lead to higher battery temperatures during run time, as compared to trucks with exposed battery compartments, and may lead to interrupted charge cycles as the battery temperature tends to exceed the maximum allowable limits. Truck manufacturers ought to consider venting options to allow the batteries to run cooler or allow for added active cooling via on board fans to move air on top of the battery for a successful fast charge implementation.

- ***Charger Requirements*:** Fast chargers are quite different than conventional chargers in a number of respects. First, the power rating of a fast charger is 3-4 times that of a conventional charger. Note that fast chargers are available with charging rates of up to 600A. As such, fast chargers may be equipped with dual cables and dual connectors for charging rates in excess of 300A. Secondly, fast chargers incorporate advance controls that maximizes battery acceptance and actively limits the battery temperature rise. As such, a thermistor is required on the battery side. In order to feedback temperature measurement to the charger, connectors with auxiliary contacts are needed. Available connectors with auxiliary contacts include the SBX and the Euro types, although the Euro type connectors have more durable auxiliary contacts.

- ***Electrical Infrastructure Requirements:*** Since the power rating of a fast charger is quite higher than that of conventional chargers, the plant electrical infrastructure must be capable of powering the fast charger fleet. This also entails proper sizing of the electrical outlets for each charging position as well as distributing the power to various fast charging locations throughout the plant.

- ***Charger Placement:*** Since fast charging entails charging at every opportunity possible, it is highly recommended that the chargers are placed very close to the work areas (distributed throughout the plant). This is contrary to conventional charging where chargers are installed in one area, namely the battery room. Careful review of the plant operation and the work flow throughout the plant will allow for better implementation of fast charging. Fast chargers are commonly placed near break areas, receiving and shipping docks, and work cells.

Fast Charging Battery Concerns

Although fast charging is becoming a main stream charging technology, many still hold negative impressions about this technology. One of the most common themes one hears is that "fast charging is not good for the battery". The reason for that, many would say, is the higher temperature the battery experiences due to the high charge rates, which would lead to shorter battery life. In fact, many go further to conclude that the expected battery life in fast charging is three years ore less as compared to five years in standard charging applications. At a first look, these comments are sound and reasonable given that many were brought up on these principles. However, these claims are not that accurate.

First, it is true that a battery experiences to higher operating temperatures in fast charge applications. The only caveat is that the higher temperature is not due to the high charging rates but rather to the lack of cool down periods. Note that in conventional charging, the batteries on average get a rest ort cool down period which reduces the battery operating temperature. In fast charging, and since the battery is either in use or being charged, there are limited cool down periods except on weekends after a equalize cycle. As such, the average operating temperature of the battery increases throughout the week. Note

that the temperature rise due to the higher charge rate of fast chargers is not much different that that of conventional chargers. In fact, most of the temperature rise during the charge process takes place during the gassing phase or finish charge phase (85%-100% SOC). Since with fast charging the charge process is terminated at 80%-85% SOC, well before the onset of gassing, the temperature rise of the battery is limited. In addition, all fast chargers require temperature feedback from the battery and incorporate active controls to limit the maximum battery temperature during charge.

To tackle the claim about battery life, one needs to note that many perceive that the average battery life should be 5 years (time based) while a fast charge application, battery life is merely 3 years or less. What is missing from this perception is the fact that in conventional charge applications, the battery is used in one shift per day while in fast charge applications it is used in two or more shifts per day. Hence, and comparing apples to apples, a fast charge battery does the work of two or more batteries on a daily basis. As such, even if a fast charge battery lasts half the time of a conventional battery (2.5 years versus 5 years), it will still deliver the same amount power that a conventional battery will deliver over a longer time period.

To present the point in a difference way, if one would calculate the total amp-hour delivered from a conventional battery over its life time, the fast charge battery would deliver the same amp-hours or even more during a shorter time frame. As such, a customer is still getting the full power he paid for out of both batteries. This in fact gives rise to a new warranty concept that is not time based but rather energy throughput based, or what we refer to is ***Warranted Amp-Hours***. Converting a typical conventional battery warranty of 5 years where the battery is expected to deliver 1500 cycles with 80% depth of discharge, the resultant Warranted Amp-Hour value is: 80% x 1500 x Battery Rated Amp-Hour Capacity or 1200 x Battery Rated Ahr Capacity. For example, for an 850Ahr battery, the battery is expected to deliver 1.02 million amp-hours over its life time. As such, battery OEMs can offer an alternate warranty for the same battery of 1.02 million amp-hours or 5 years, whatever comes first. This will definitely take the confusion regarding battery life on fast charge applications.

Another Note on Fast Charge Batteries: Vented vs. Non-Vented

Another variation to battery construction in fast charge applications is a vented versus non-vented trays. Some believe that a vented tray reduces battery heating (temperature rise) due to the added vents in a battery tray. Although this may be a valid argument in some applications, the extent of the benefit of vented trays depends on the application itself.

First, one need to understand that the vents in a battery tray don't come at no cost. Normally in fast charge applications, we recommend to use the largest battery size that can fit within the truck battery compartment (largest fuel tank possible). This is done to ensure that even under heavy use or missed charge opportunities (which happens); the battery state of charge doesn't go below 20%. If it does, then the battery internal impedance will increase which increases battery heating and may cause damage to the battery. So in a sense, we need to build as much reserve as possible to reduce the burden on the battery.

With vented trays, the battery capacity is reduced since you would have to settle for 2 less plates in each battery jar to allow for vents between the battery cells. So, if a non-vented battery has 21 plates, the vented version will have a maximum of 19 plates to allow for vents between the battery cells. As such, the battery capacity will be lower by 10%, or we will be sacrificing capacity for the vents. As to whether the 10% capacity loss is significant or not depends on the application. For example, if we can maintain the battery state of charge above 30% all the time with a vented tray, then the vented tray may perform better than a non-vented tray. If, however, one need that additional capacity due to limited or missed charge opportunities, then a non-vented tray will offer an extra 10% margin. Otherwise, running a battery (vented or not) at a low state of charge leads to additional heat generation due to the higher internal resistance. Some may claim to offer a vented tray without capacity loss. This is only possible if the plates are made thinner, which leads to higher battery resistance and additional heating thus giving up the benefits of vents in the first place.

On final note on vented trays. The benefits of vented trays may end being negligible in trucks that have poor venting, i.e. the battery compartment is fully sealed. In poorly vented trucks, the air within the battery vents will be stagnant and will be ineffective in conducting heat away from the cell. Active or forced air cooling may offer a more effective solution without sacrificing capacity.

Is Fast Charging for Everyone

Not necessarily. Although many applications seem to be good fast charge candidates, they may end up being not suited for that. First, there has to be ample opportunities to charge the battery within each shift (or in between shifts) to recoup the amp-hour used. In some applications, and although there is ample time within the day top return all amp-hours used, most the charge time available is after the end of the second shift, i.e. two shifts are operating back to back with minimal charge opportunities. As such, unless the operation can be modified to allow for more breaks (charge opportunities) within each shift, such applications may not be suited for fast charging.

Secondly, one needs to allow for at a finish / equalize charge cycle at least once a week, a process that may take up to 8 hours. Heavy three shifts or 24/7 usage may not be a candidate for fast charging if a finish / equalize charge cycle can't be accommodated. However, hybrid opportunity / fast charge / battery changing solutions may be viable and may offer dramatic reduction in the number of battery changes per day, which can significantly improve productivity.

Are You a Fast Charge Candidate?

Well the litmus test is simple. If you operate (plan to operate) battery powered trucks at least 1.5+ shifts per day and do (or anticipate) at least one battery change out per day you may be a candidate for fast charging. Now the next step is to fully understand the operational profile of the trucks / batteries to discern whether you can actually use fast charging. This can be established through a power study where the battery / truck operation is monitored throughout the week. For the collected data, one can establish whether there are adequate opportunities for fast charging through the shift or day as well as a weekly opportunity to perform a finish / equalize cycles. Once that is established, the question of whether you are a fast charge candidate can be affirmed.

Final Word

Fast charging is a technology that has many advantages and can allows users to realize significant savings. For the successful implementation of fast charging, one needs to consider a number of factors and develop a good understanding of what this technology can offer and what the limitations are.