FUTURE POWERING CHALLENGES.
IS THE INDUSTRY READY TO ACCEPT CHANGE?

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Abstract

In the not too distant past the selection of a battery and charger for a standby application was a relatively simple process. The largest markets for these power systems were in Telecommunications and the Utilities each with a specific set of standard requirements.

Today in our interconnected world with its obsession for 24/7 connectivity, the requirement for standby power continues to grow, but how relevant are the products and practices that we know and trust in this new marketplace.

This paper will examine the challenge of powering this next generation of integrated infrastructure.

From solar powered data centers, to a 5G network with points of presence on every third available pole in some cities, do the traditional system configurations match the actual user requirements?

With the introduction of Lithium and other new battery technologies, are the charging systems capable of meeting the required charging profiles to minimize the risk of fire and other potential catastrophic events?

The paper will close by looking at a new category of product being introduced by some manufacturers to meet some of these challenges. The question is, are we ready to accept the changes to our established practices that will be required?

Introduction

Since the end of World War Two, the world's population has seen many changes that have affected every aspect of life. In that time, we have had five generational changes and in each one the pace at which we live our lives has increased. The driving force behind most of this, for better or worse, is our ability to communicate on an almost instantaneous basis. To support this phenomenon there is an increasing demand for batteries that are smaller, lighter, more powerful and safer. Initially, the applications for these batteries were for portable applications, but today, they are increasingly being used in applications typically reserved for lead acid and nickel cadmium batteries. The question is, has our ability to charge and distribute that power kept pace?

Early Charging Technologies

In 1859 Gaston Planté developed his first battery in which the chemical reactions that generated the electrical energy could be reversed by applying a DC voltage to the cell terminals. This established a requirement for what we now know as a battery charger. Based on an illustration in a paper written by Planté in 1883 where it shows an original Planté cell being charged by a Gramme magneto generator, it is reasonable to assume that this should be considered as the first battery charger.

By the early 1900's the vacuum tube diode was invented which could be used to convert the AC output of a stepdown transformer to a DC current suitable for battery charging. This was followed by the selenium rectifier in the 1930's, and the silicon diode in the 1950's where the charger output voltage was determined solely by the transformer design. This is still the method used by the cheap automotive battery chargers we can buy today.

But as we know, to get the best from any rechargeable battery, the voltage and current need to be more closely controlled. In 1916 a paper was published that described the method by which the output voltage of a transformer could be controlled by adjusting the saturation of the magnetic core. This requires a feedback circuit from the transformer output that allows the transformer to maintain the output voltage irrespective of the load being drawn. As the level of power required to maintain/control the output is quite small, a charger based on this technique is described as a magnetic amplifier-based charger.

1938 saw another transformer design in which the output voltage could be maintained within limits irrespective of the input voltage or output load. In this case it was the physical design of the transformer that did the control, not any external feedback. It was possible however to vary the output voltage with an external circuit and this is the basis of what we know as a controlled Ferroresonant charger.

The next change in charger design didn't come until the early 1950's with the development of the Silicon Controlled Rectifier (SCR). This device allowed the current and voltage applied to the battery to be controlled by electronics rather than the design of the transformer and as a result allowed simpler and lower cost transformers to be used. The SCR charger is still today the most widely used charger technology in the Industrial and Utility market, albeit now with microprocessor control and communications. But the Mag Amp and Ferroresonant transformer-based chargers are also still being manufactured and used in specific applications.

Switched Mode Rectifiers

The introduction of the Valve-Regulated Lead-Acid (VRLA) battery in the early 1970's, with the ability to move batteries into remote sites, created a requirement for smaller and lighter chargers. A 1959 patent for a technique by which the incoming AC could be converted to a higher frequency by switching transistors, which would allow smaller transformers to be used, became the basis for the next generation of battery chargers. Switched Mode Rectifiers (SMRs), as they are known, are now the standard in most battery charging applications throughout the world. There are exceptions specifically in the Industrial and utility applications where the requirement for a smaller footprint is not as important, and the concerns about fan failure remain. This is particularly true in the United States where the preference for the older technologies still rules. The real question is, are any of these chargers capable of supporting the new battery technologies being developed and introduced into the market?

New Battery Technologies

One of the reasons that lead acid and the nickel cadmium cells still comprise most of the standby battery plants is because, if properly installed and maintained, their performance is understood. As a result, they are under increased regulatory pressure, and in many cases targeted for replacement by regulators. But that is not the only reason why users are looking at new battery technologies. Weight and space are becoming more important in a system configuration. The energy density of the latest products is becoming a key factor in battery selection. Table 1 shows the range of energy densities that can be found in four of the commercially available battery chemistries when compared with Lead Acid.

Apart from energy density, each of these battery types is also differentiated by their operating voltages at a cell level. This means that the number of cells required to support the typical operating voltage of lead acid batteries will be different.

Table 1

Chemistry	Energy Density	
	Wh/kg	Wh/L
Lead Acid	30-40	60-75
Nickel Metal Hydride	60-120	400
Nickel Zinc	70-110	200-360
Sodium Nickel Chloride	140	280
Lithium	90-220	333-600

Table 2 shows the number of cells required for a typical 48V application along with their upper and lower voltage operating limits. The number of cells chosen to meet the 48V requirement were not based on the 1.75V level specified for lead acid but rather on the lower limit of a -48V input DC-DC converter which is a more typical load in today's applications.

Table 2

Chemistry	Cell Voltage Range		No of Cells	String Voltage Range	
	Min	Max		Min	Max
Lead Acid	1.75	2.33	24	42	56
Nickel Metal Hydride	.9	1.4	40	36	56
Nickel Zinc	.9	1.8	40	36	72
Sodium Nickel Chloride	2.2	2.7	20	44	54
Lithium Iron Phosphate	2	3.65	18	36	65.7
Lithium Nickel Cobalt Aluminum Oxide	3	4.3	12	36	51.6

Based on this, it is apparent that for at least one battery, the upper voltage limit of the existing chargers will not meet the preferred charging profile. Lead acid batteries in standby applications spend most of their life operating at a fixed float voltage, which compensates for the self-discharge and allows the battery charger to also be the primary source of power for the load. This is not the case with these new batteries; to achieve their optimum performance it is required that they be operated under a specific charge control regime.

Charging Profile

The charging profiles for these currently available batteries are all different.

Nickel Metal Hydride batteries prefer a constant current charge with the ability to detect the point at which the battery has reached full charge. Determining this point is one of the challenges. A full charge is when the battery voltage changes from increasing to decreasing; and also the rate of rise of temperature rapidly increases. Once it has reached full charge the battery would prefer to be taken off charge and be allowed to self-discharge to a defined point at which it is put back on charge and brought back to a fully-charged state.

Nickel Zinc batteries also require a constant current charge, but unlike the Nickel Metal Hydride battery they are charged at a constant current until they reach a specific voltage, at which point it changes to a constant voltage and maintains that voltage until the charging current drops to a specified level. Then, like the Nickel Metal Hydride battery, it prefers to be taken off charge until it has discharged to a specified limit, at which point the cycle is repeated.

Sodium Nickel Chloride batteries are completely different. They operate using a salt-based electrolyte that must be maintained at a minimum temperature of approximately 265^{o}C for the battery to work. When the battery is being charged, metallic sodium is expressed from the salt solution and deposited on the inner wall of the cell container; and during the discharge it is converted back into the salt solution. To manage the process of heating the battery to the operating temperature (and maintaining it there) requires a battery management system, which must also provide certain controls over the charging process.

Unlike the other battery chemistries discussed in this paper, there is no single operating profile that will satisfy all the variations of the Lithium batteries currently in commercial use. As can be seen in Table 2, there is quite a variance in the operating voltage of the two lithium-based batteries listed. Ensuring that a lithium-based battery operates within its required parameters is essential as they can become unstable if the voltage across each of the cells is not in balance during both charge and discharge. Like the Sodium Nickel Chloride battery, they also require a dedicated battery management system, this one to ensure that the cells remain balanced and operating under conditions that will minimize risk.

It should be noted that the battery management systems do not generally control the overall charging voltage of the battery string; that is the responsibility of the charger. The function of the management system is to balance the charge voltage across each of the cells. It is also responsible for removing individual battery packs from service if it is no longer able the keep the cells within the pack within safe limits.

A Next Generation Charger

It is clear if we are going to satisfactorily support all these new battery chemistries, both the current models and those in the future, the capabilities of our existing chargers are not best-suited to these new requirements. So, what are the features that this next generation of charger will require?

As we have already established, each battery will require a specific charge profile, which can include periods of both constant current and constant voltage charging and that is a key requirement. The charger will also have to detect the point at which the charging regime is required to move to the next stage, using the values of battery voltage, current and temperature. For those batteries that have their own battery management capability, there would be a clear advantage if both the management system and the charger could communicate. Probably the simplest way to do this would be for the charger to retrieve the available data from the management system and makes changes to the chargers' operating parameters to match the charging requirements of the battery, based on a predetermined algorithm. The alternative is for the management system to control the charger by sending commands to change the chargers' operating parameters.

This concept of a smart programmable charger may also be able to solve another problem that these batteries face if large quantities are to be placed in service. In a paper presented at last year's Battcon conference, we were introduced to the latest restrictions on the installation of batteries as published in the 2018 editions of both NFPA 1 and the International Fire Code. In both documents there are now restrictions on the quantities and capacity of all new technology batteries that can be installed at a single location. The permissible locations for these batteries within the buildings is also specified to be no more than three floors above street level or two levels below. These restrictions came into force for some jurisdictions as early as the first of January 2018, and the objective is to protect emergency personnel in the event of a battery fire. These provisions are obviously driven by the publicity over Lithium fires and a lack of understanding about the other battery technologies. This has major implications on how standby power is provided within high-rise offices in the major cities, so perhaps the use of smart chargers that limit the ability of a battery to catch fire could be an alternative.

Power System Design

Although battery chargers are often used in a standalone configuration charging one string of batteries, there are many applications where there are DC plants with multiple chargers operating in parallel or incorporated within a UPS system. In these applications, irrespective of the number of battery strings involved or their age and condition, all the batteries are subjected to the same charging voltage. Figure 1 shows the standard configuration with a charger, a battery, and the output is either used to power an inverter to supply AC when it's a UPS, or directly to power DC loads. In this type of configuration, even with smart chargers, there is no way to match a charger with an individual battery string.

Figure 1

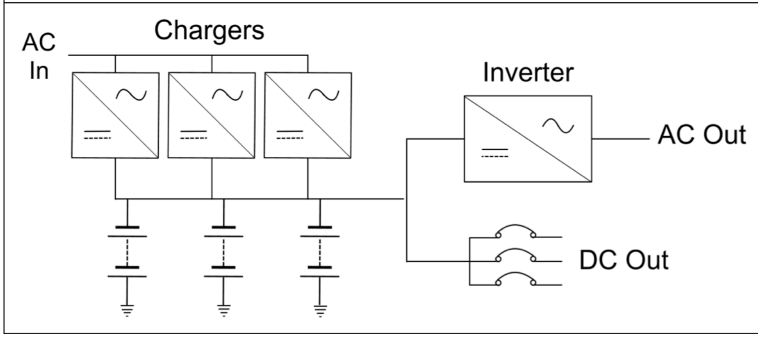
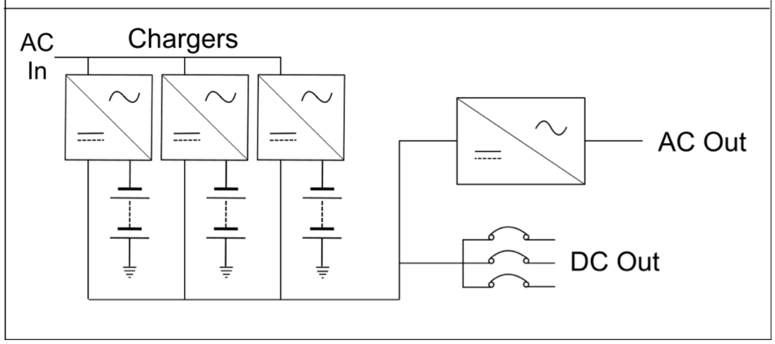


Figure 2 shows an alternative approach where the individual battery strings are paired with one or more chargers (if required) and gives us the ability to match the chargers to the operating characteristics of each string. As the chargers will still have to operate in parallel and provide the current required to support the load, there will have to be a separate controlled charging output in each of the chargers.

Figure 2



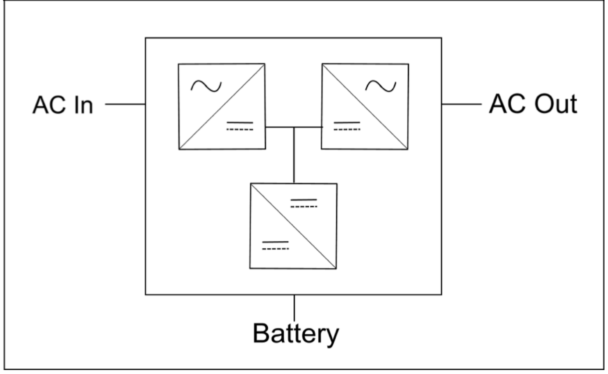
Even if we do introduce smart charging into bulk power systems, is this idea of centralized power the ideal configuration for many of applications we are now required to support?

For many years telecommunications systems have been powered by low voltage DC and data centers have used AC power. As communications and data have merged, there have been many arguments as to whether the backup power in these integrated facilities should be AC or DC. Although DC seems more logical in view that all modern electronics work on low voltage DC, including all the displays and printers. The argument against adopting DC has been the cost and limitations of distributing 48V DC power within a large facility. To counter that argument, there have been a number of papers proposing the use of distributed DC power systems. This includes the author's own paper at Intelec in 2004 and another one at Battcon in 2012. The idea was that if the power was located closer to the point of use, the cost of distribution was lowered, and the impact of a power system failure was localized to the number of racks powered by that power system. One of the arguments against this was the idea that we still required 4 or 8 hours of battery reserve, and the number of batteries that would be required to meet that would have required too much space. In the meantime, both Google and Facebook have adopted the distributed power concept in several of their data centers, but are only providing 15 minutes of backup and using generators to support a longer power outage, which is a standard data center practice. Facebook made both the power supply and server designs. They had developed open source, and established the Open Compute Project to encourage industry participation, but it appears that none of our established DC power system vendors have seen fit to commercialize in a large way the distributed DC concept, particularly within data centers.

Next Generation Power Systems

It would be unfair to say that there have been no developments within the standby power industry over the last 10 years but most of it has been focused on inverters and UPS. This is understandable, considering the growth in cloud computing and the associated power-hungry data centers. The most important is probably the ability to parallel multiple small inverters into systems of up to 100kW and higher. Data centers are under enormous pressure to reduce their consumption of electricity and this level of granularity when sizing a system allows it to closely match the specific load while still having the ability to expand as required. Unlike a conventional DC to AC conversion where the DC power required will always be greater than the available AC power out due to inverter efficiency, as we can see in Figure 3, this next generation of inverters consists of three isolated converters. The first converts the incoming AC to a high DC voltage. The second converts the high voltage DC to AC, which totally isolates the load from any input transients or other conditions. The third converter converts the battery voltage to the same high voltage DC which will allow it to power the output inverter in the event of a utility failure. To eliminate the requirement for the battery to provide transient support, the high voltage bus has a large capacitance incorporated within the design, which effectively isolates the battery from any load transients which can shorten battery life.

Figure 3



From a planning and efficiency perspective, the major advantage is while you still require the battery capacity to support the AC load, you only require the additional DC capacity to recharge the larger battery and not the power to run the inverter.

So where will we go from here? There continues to be a focus on the need to decentralize standby power with all the push to make everything “SMART”, and in many cases these new applications need both AC and DC. As with many things today, the proposed solution is not new, it is based on a concept originally introduced by Lorain Products in the late 1980’s with a product called the Constac. The idea was, you had a bi-directional unit which was both a charger and an inverter and that allowed you to power both AC and DC loads from the product. The best way to describe it would be a hybrid power system in a box. Of the two manufacturers who have already released products based on this hybrid approach, each has taken a different path. One took a charger and made it bidirectional so when power is lost it becomes an inverter. The other took the inverter module described above and made the battery interface converter bidirectional so it can now also charge the battery.

Conclusions

There is no question that the number of potential applications for which standby power systems are required is evolving rapidly. This also applies to the next generation of customers, and their perception of what that power system should be capable of. At a recent International trade show, during conversations with a cross section of attendees, it was clear there was general dissatisfaction with the implementation of standby power systems, whether it was a starter battery for a generator or a multi megawatt UPS. The idea that a battery warranty is invalid because the settings of the charger did not match the battery requirements is difficult for them to understand considering how little automation it would take to ensure this doesn’t happen. The consensus appeared to be that the charging circuit, the battery and the required control and monitoring capability should be an integrated package responsible for charging the battery in a way that ensures that both life and safety are maximized.

This clearly expands on the required functionality of smart charging circuits beyond what is already outlined in this paper. However, this increased level of control can essentially be software-based, hence the idea that future hardware used to provide standby power is simply a collection of modules that are either AC-DC or DC-DC converters under the control of a single software package.

The real challenge will not be in either the hardware or the software, but in establishing a consensus about the criteria under which the smart chargers will regulate the battery charge. Anyone who has ever sat on an ESSB committee will appreciate that challenge.

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