EAGLE EYE
TECHNICAL NOTE

Title	**Is It Time to Take a Serious Look at Convection Cooled Switched Mode Rectifier/Chargers Again**
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Abstract

Switched Mode Rectifier/Chargers (SMRs) are the dominant method of charging stationary batteries for telecommunications (telecom), information technology (IT) and other standby power applications. The vast majority of these are forced air cooled. In North America, the exception is with the utility companies who still favor older linear technologies, mainly Silicone Controlled Rectifiers (SCRs).

So why the reluctance of utility companies to adopt the lighter, more efficient and user-friendly SMRs? This paper will explore the issues and argue the case for a second look at SMRs, in particular, convection cooled SMRs.

The author uses his experience in working with all the major user groups and also with the various charger technologies, first becoming familiar with SMR chargers with their popular acceptance in the late 1980s. He understands the reasons that utility users are reluctant to change and thinks that many industrial and utility users are “missing the boat” by not adopting modular power systems using modular SMR technology and the benefits they bring. The objective of this paper is to be an educational thought changer.

Topics discussed include: history, reliability, efficiencies, maintenance, pros and cons, and costs.

Introduction

The author, before his recent retirement, spent a good part of the previous five years working closely with utility companies and their battery back-up systems. This work included sizing, configuring, surveying, maintaining, and installing both new and replacement systems. Having worked for many years with telecom and IT users, he kept wondering why the utilities used a different approach to providing battery back-up. This paper is a brief discussion of that question.

A Brief History

First of all, a little history of battery rectifier/chargers. This is the preferred name as these devices have to perform both functions, and that is, rectify alternating current (ac) to direct current (dc) and, at the same time, be capable of charging a battery. When stationary batteries are in use, a charge has to be maintained on them whether it is to compensate for self-discharge or to recharge the battery after discharge. The dc output of the rectifier/charger must be well filtered and regulated to be able to do this without having a detrimental effect on the battery.

The Magnetic Amp

Early in the last century, a device called a magnetic amplifier was invented to magnify electrical signals and came to be used in place of vacuum tube amplifiers, as they were more robust. This “Mag Amp,” as it became to be known, was a solid-state device, and with high reliability, it became the workhorse for battery charging. Indeed, these high reliability mag-amp based chargers are still being used today.

The Controlled Ferro

The 1930's saw another transformer design in which the output voltage could be maintained within the required 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 Rectifier/charger (CFR).

The SCR

During the 1950s, Bell Laboratories developed the Silicone Controlled Rectifier (SCR), and this was used along with conventional transformers to come up with a new rectifier/charger technology which became known as the SCR charger. This technology allowed the output to the battery to be electronically controlled rather than through the design of the transformer. This also allowed for simpler and cheaper transformers to be employed. This basic technology with many refinements along the way, such as microprocessor control and communications abilities, became, and still is, the workhorse of the utility and industrial market segment today. The magnetic amplifier and ferroresonant transformer-based designs are still being manufactured and used in specific applications.

The Times Were a Changing

During the late 1970s and early 1980s, things were happening in the deployment of telecom systems and the computing industries. There were also new developments in battery technologies. These things combined to spur a new approach to battery charging.

In the US, on the telecom side, the Bell System, which was owned by AT&T, had a virtual monopoly of providing telephone service. Because of this total control and public resentment, an antitrust lawsuit was filed, United States v. AT&T, in an attempt to break up this monopoly. A compromise was reached by AT&T, and as part of the settlement of this legal action, on January 1, 1984, the Bell System was broken up into smaller Regional Bell Operating Companies (RBOCs) or "Baby Bells."

Because of the settlement, there were several competitors waiting in the wings, such as MCI and Sprint, and manufacturers of communications switching equipment, such as ROLM. One of the main outcomes was that the RBOCs no longer had to buy equipment, including battery backup systems, from AT&T. Also, the new start-up communications providers were able to build up their networks with more modern and innovative equipment. As a result, the industry was moving away from large, centralized, switching centers, and deploying more and more network equipment outside of the large telecom central offices.

In tandem with the developments in the telecom industry, the IT industry was also experiencing change. Large computer mainframes and their associated support equipment were shrinking, and powering techniques and demands were changing. Distributed computing was also being used, and because of the increase in processing capabilities, smaller computer systems were being installed in locations other than dedicated, large computer rooms.

Some other things that were also happening that also impacted powering methods and battery backup techniques. One was the rapid development in deploying cellular (mobile) radio. During the late 1980s and early 1990s, this wireless technology was being deployed at a rapid rate and battery backup system providers where anxious to keep pace. The same applied to the cable TV deployment with cable head ends and networks being built.

The Perfect Storm

in the author's opinion, having lived and worked through it, all of these things happening basically at the same time created the "perfect storm" in the battery backup field.

So, how do these events affect battery charging and batteries? It was basically customer driven. Because of the remote locations, residential locations, customer premise locations (communications equipment being located at the users' premises), etc., users were asking for smaller, lighter, cheaper, more user friendly and easily maintainable equipment. Well, it just so happened that there were two other breakthrough innovations that were happening at the same time.

There was a move on both sides of the Atlantic to come up with a more user-friendly lead-acid battery, one that did not have liquid electrolyte or was subject to out-gassing. In Europe, the first gelled electrolyte battery was developed by Sonnenschein in Germany. The first Absorbed Glass Mat (AGM) battery was developed by Gates Rubber Company in the US. A number of other manufacturers jumped on the bandwagon, including Chloride and Tungstone in the UK and Gould National Batteries (GNB) in the US.

They developed and refined the Valve-Regulated Lead-Acid (VRLA) battery we know today. In the UK this was stimulated by British Telecom specifying this type of battery to support their new telecom technologies. In North America, GNB took a lead in developing larger format units and marketing these VRLA Batteries. However, there were many teething problems and customer satisfaction was poor. Indeed, much of this led to the formation of the International Battery Conference "Battcon™ in 1996.

In a similar manner, much of the development of rectifier charging technologies was user driven, too. Just like with VRLA batteries, customers wanted something smaller, lighter, cheaper, more user friendly and easily maintainable. They also wanted equipment that was less noisy, both electrically and physically, than the existing CFR and SCR equipment. This was the introduction to Switched Mode Rectifier (SMR) battery rectifier/chargers.

Early Switch Mode Technology

This technology was built off a development from the late 1950s, using a method in which the ac input to the rectifier was converted to a much higher frequency using switching transistors that allowed smaller transformers to be used. The SMR charger was the answer to the user demands.

Certainly, they were smaller, lighter, more user friendly, quieter and in a modular configuration, and easier to maintain. However, the SMR chargers had some early drawbacks in that they were still quite bulky when convection cooled, and the earlier versions were not as efficient as they are today and managing heat dissipation required sizeable heat sinks. The answer was to make them forced air cooled.

This certainly made the SMRs smaller by eliminating the large heat sinks but introducing fans caused some other problems. The fan became the highest single point of failure, and the ingestion of dust and dirt and clogged filters caused other problems, too. In addition, the fan load affected efficiency. A development called "fan-on-demand," where the fan was only activated if the unit temperature rise requires the fan to run, was used by some manufacturers in order to extend fan life.

Fan reliability and efficiency has also improved over the years, with some having a lifespan approaching 20 years. Fan cooled SMRs now serve the majority of battery charging requirements. However, there is one exception which leads, albeit in a somewhat lengthy way, to the main point of this paper. That exception is the use of SMRs in industrial and utility application.

The Reluctance to Change

So why was this market segment reluctant to move with the times? There were several reasons. For a start, those industries were traditionally reluctant to change and preferred to stick with what worked. There was little or no change in the equipment that was being powered, nor was the load equipment downsizing or change of location outside of the controlled environments that they operated in.

There was no exposure to non-qualified personnel. Space was not a problem then, so there was no need to make things smaller, lighter, etc. There was usually plenty of manpower and technicians to maintain the equipment. There was no move to use the new technology VRLA batteries as they rightly preferred to stay with the proven reliability of Vented Lead-Acid (VLA) batteries.

SCR chargers have over the years, proved to be a very reliable means of charging batteries; however, SCR chargers had and have some drawbacks. They are not as efficient as SMRs, which is being scrutinized by regulatory agencies. Regulated utilities may be exempt, but for how long?

One example is the State of California, which in 2011 mandated in Section 25402, subdivision (c), of the Public Resources Code[1] that the "California Energy Commission reduce the wasteful, uneconomic, inefficient, or unnecessary consumption of energy by prescribing standards for minimum levels of operating efficiency of appliances whose use, as determined by the Commission, requires a significant amount of energy on a statewide basis."

At this point in time, the mandate only applies to devices under 2kW, but watch for this to change. The author believes that the states of Oregon and Washington also have similar mandates. Almost all modern SMRs would meet this mandate – not to say SCRs would not – but the fact is that SMRs are more efficient. See Figure 1 and Table 1.

Efficiency

Figure 1 below is a graphic representation of the difference in efficiencies between a typical SCR charger and SMR charger.

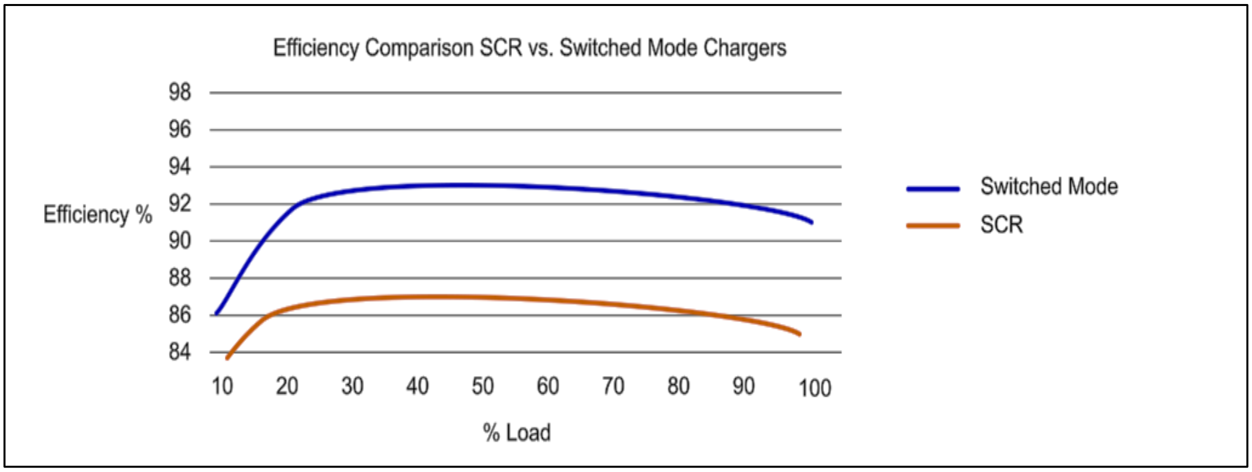

Figure 1

Efficiency is a measure of the useful power input divided by the power consumed.
100 Watts in, 90 Watts out = 90% efficiency and 10% efficiency loss.

This graph represents two 130 Volt 30 Amp rectifier/chargers, which equals 3,900 Watts output. At an 85% efficiency at full load, the SCR charger would require 4,588 Watts ac input. The SMR charger at full load at 91% efficiency would only require 4,285 Watts ac input. This translates to a difference of 303 Watts which is 2,654 kW per year. At a generous cost of $.15 per KW/hr., this represents a cost savings of $398 per year, or more realistically, $3,980 over a 10-year life span. This does not include the significant cost savings related to maintenance and repair.

Table 1. Results of a laboratory test of two similar capacity rectifiers

	SCR Measured Values	Switch Mode Measured Values
	25A Full Load	**25A Full Load**
Output DCV	130.00	130.00
Output DCI	24.46	24.40
Output Wattage	3179.80	3172.00
Input Voltage	240.00	240.10
Input current	26.27	14.40
VA	6290.00	3445.00
VAR	3590.00	-904.00
Power Factor (DPF)	0.73	-0.965
Power Factor (TPF)	0.588	-0.960
Input Wattage	3709.00	3309.00
Efficiency	0.86	0.96

Table 1 shows the results of an actual laboratory test of an SCR charger and an SMR charger of similar output capacities. The SMR charger, like the SCR unit, was convection cooled. This test clearly verifies the assumptions detailed in the example under Figure 1 above. At full load, the efficiency difference is 400 Watts which is 3,504 kWhr/year. But realistically, the rectifier/chargers are not going to be running at full load, so taking the example of the 4 amp load in the table above, the difference in efficiency is only 116 Watts which is 1,016 kWhr/year, which is still a significant power saving. As stated by the Electric Power Research Institute (EPRI) [2] "Switch mode chargers of any topology are generally more efficient than the other types of charger."

Ripple?

Another problem with SCR chargers is that they sometimes can generate unsmoothed dc voltages, causing a higher ripple voltage and current to be imposed on the battery. It is not fully understood exactly what all the effects of this ripple are on the battery, especially VRLA batteries, but battery heating is thought to be a concern.

SCR chargers are typically connected to VLA batteries, which are more tolerant to ripple, but what if the industrial industries are persuaded to use the more environmentally friendly VRLA batteries? Don't think that this is not possible, as there have already been some moves in this direction. Indeed, some regions and countries are attempting to do away with lead-based batteries entirely. That is certainly going to have an impact on stationary battery charging, but that is the subject matter for another paper.

Acceptance?

While rectifier/charger size, or the space that is occupied, hasn't been a problem in the industrial and utility industries so far, with the adoption of NERC TPL-001-5[3] and the requirement for back-up power system redundancy, available space is now becoming a problem. And with the perception that fan cooled SMR's have reliability concerns, why not revert to the original type of convection cooled SMR units that were first utilized in the 1970s and 1980s? They were bulky but not as large as SCR chargers and didn't have the communications and microprocessor control capabilities of today's SCR chargers.

So, if these capabilities were added to a modern, high reliability, convection cooled SMR charge that vaguely looked like an SCR charger, that would operate in industrial environments and had the reliability equal to or superior to that of SCR chargers, could they be accepted by the industrial/utility segment? The author believes that they would.

Reliability

Typical industrial and utility installations that the author has seen consist of a single SCR charger supporting a single VLA battery string. A few have dual SCR chargers, either individually connected to the dc bus or load sharing, and a few have VRLA batteries, some of which are two or more parallel strings.

Where there is only a single charger, the risk is obvious. If that single source of power fails for any reason, then the load is going to be running on battery. A well-engineered system will probably only have about 8 hours of battery reserve. So, unless there is a spare charger on site, the probability is that it will take more than 8 hours to fix or replace that charger. If it has to be replaced, because of the weight and for safety reasons, it would typically be a two-man job.

The risk to the load being compromised is also obvious. The author, coming primarily from a communications and IT background, could not understand why there was not more redundancy built into the overall system. There is usually a similar situation with the battery if only a single string is installed. If it has to be taken offline for any reason and there is a commercial power aberration, the load is at risk. Shouldn't a well-engineered, fault tolerant power system have the following features?

- Dual ac inputs to the rectifier/charger(s)
- Redundant paralleled rectifier/chargers
- Two or more battery strings connected in parallel
- The ability to operate if there is a failure in the control electronics

Other redundancy features that eliminate a single point of failure are outside the scope of this paper.

The ace in the hole when it comes to SMR chargers is that they are easily parallelable and can be packaged into a modular redundant configuration. Depending upon the size of the load, including battery recharge, an SMR system can be configured so that the total charging capacity can be supported by one or more modular rectifier/chargers and an additional unit added to make the system redundant.

Here is a typical example of a scenario. Say the load including battery charging requires 20 amps. If an SCR charger is to be used, then the rectifier/charger must be at least capable of supplying 20 amps. If redundancy is required, then another 20-amp unit must be installed. If a forced load sharing feature is not available, then it is possible that one rectifier/charger will be doing all the work and will probably fail before the other.

Indeed, would there even be an indication that the "spare" rectifier/charger would even work when called upon? In addition, if load sharing, depending at which point in the efficiency curve they are individually running, overall efficiency may suffer. If for some reason the load increases, such as with the addition of more equipment, then a third 20-amp rectifier charger must be added in order to maintain redundancy.

If a modular, convection cooled approach using an SMR charger is taken for the same 20 amp load, it could be configured as follows. Say the modular rectifier/charger is capable of 4 amps output, then 20 amps ÷ 4 amps = 5, which means that five 4-amp units would be required to supply the load. In order to supply redundancy, only one more 4-amp unit would be required and not another 20 amp unit as for the SCR charger example. If the cabinet housing the modular SMR chargers is so designed, it could accommodate two or more ac inputs and dc outputs. With suitable onboard electronics, forced load sharing and other features such as remote battery sensing and temperature compensation would be afforded.

Serviceability

Another big advantage in using the modular SMR charger approach is the serviceability. Since all the modular power units are hot swappable, if one module fails, it can be replaced with a new unit within a few minutes by a relatively unskilled person. This also means that the rectifier/charger system remains in full operation, supporting the load during the repair. This unit swap out can also be done without any exposure to live parts, a possible arc flash incident, or electrical shock.

Although, not so important in industrial applications, the convection cooled SMR charger is acoustically quiet, whereas the SCR charger is inherently audibly noisy because of the transformers and chokes, and this noise can increase as the SCR charger ages.

Lastly, the author took a look at pricing or cost per watt and it is very much dependent upon the electrical size of the system, but in most cases it was pretty much parity. The same is true for energy density.

Summary

While SCR chargers are very well established with a proven reliability, there are some drawbacks, mainly with regards to the cost of redundancy, maintainability, scalability, and servicing. It is the author's opinion that when all the pros and cons are considered, a battery backed power system supported by SMR chargers is superior in most ways to a power system based upon SCR chargers.

References

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3. Federal Energy Regulatory Commission (FERC) 888 First St. NE, Washington, DC 20426
4. Table 1 and graph data supplied courtesy of Lester Electrical of Nebraska Inc that manufacture both types of rectifiers.