Reducing Operating Expenses through Efficiency Upgrades and Alternative, Renewable Energy Sources

An Operational Practice Prepared for the Society of Cable Telecommunications Engineers

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1. Introduction

The Cable industry, like many others, is reliant up on electricity to power equipment and provide service to its subscribers, but like most commodities, the cost of power is persistently rising. Reducing Operational Expenses (OpEx) is a key to company profitability and survival, and power makes up a significant percentage of OpEx. Reserve power in the form of battery or generator capacity is a key part of providing a superior Quality of Service, and requires efficient power conversion equipment to ensure continuity of service and minimize OpEx.

This paper will look at advances in power conversion equipment to improve efficiency as well as alternative sources of power, such as Solar and Wind power. We will examine different power architectures to see how efficiency improvements can reduce OpEx and look at upgrade scenarios that can generate direct and indirect savings, without the need for total power system replacement.

This paper will also examine several of the challenges encountered in tapping into renewable energy sources and show how, with appropriate trade-offs and innovative engineering, successful systems can be designed and deployed. Actual deployments utilizing solar, wind, and various generator technologies will be shown and discussed along with the engineering solutions that made them successful.

2. Rectifier Advances

Rectifier technology has made tremendous improvements over the last few years, with rectifier sizes reduced by one to two orders of magnitude. Efficiencies have improved dramatically, with losses reduced by as much as 75%.

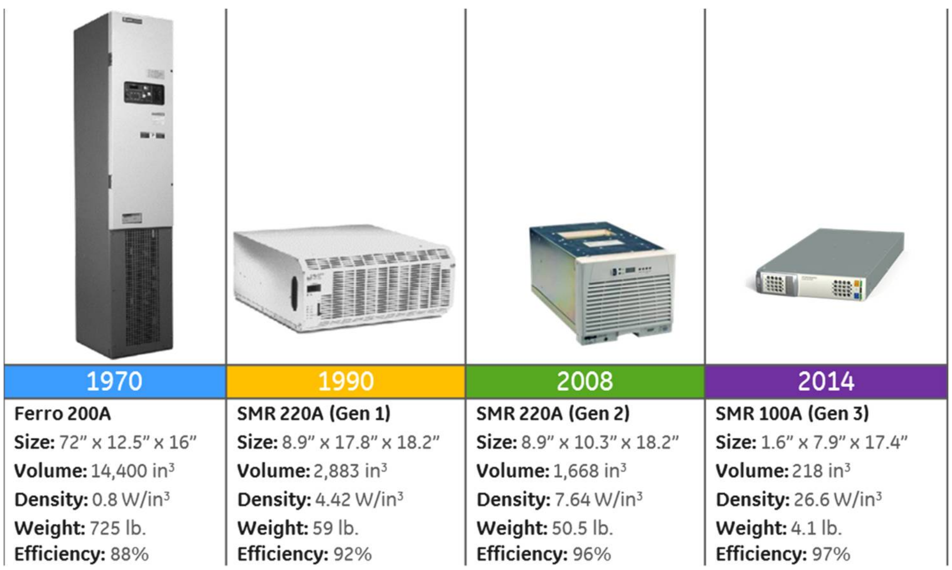

Figure 1 - Rectifier Advances

When looking at rectifiers and their advances over the years we will compare Ferro Resonant technologies and the subsequent generations of Switch Mode Rectifiers.

2.1. Ferro Rectifiers

Early Ferro Resonant rectifiers made use of large, heavy magnetics and only achieved around 90% efficiency. This combined with the significant decrease in efficiency as loading decreased led to efficiency at the system level that could be as low as 85% or less. The efficiencies of several models of ferro rectifiers are shown in the graph in Figure 2 below.

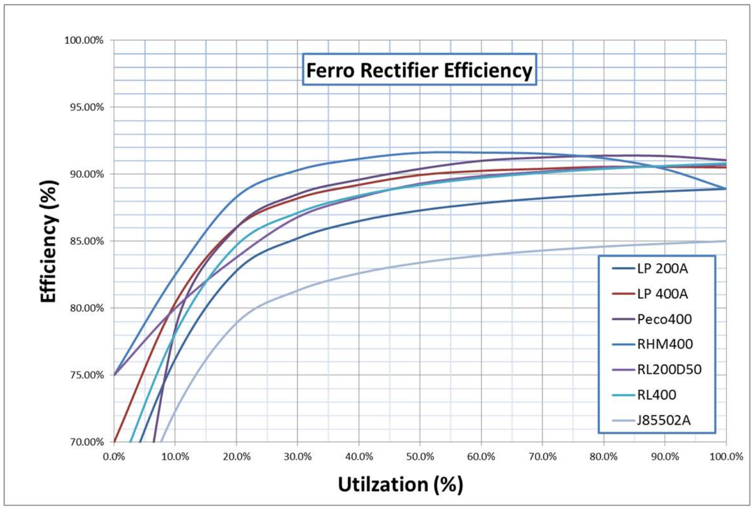

Figure 2 – Ferro Rectifier Efficiencies

2.2. Switch Mode Rectifiers

Switch Mode Rectifiers (SMR) offer significantly smaller size, thanks to higher switching frequencies and the resulting smaller magnetics. Efficiencies are also higher, and have been steadily improving as topologies have been optimized.

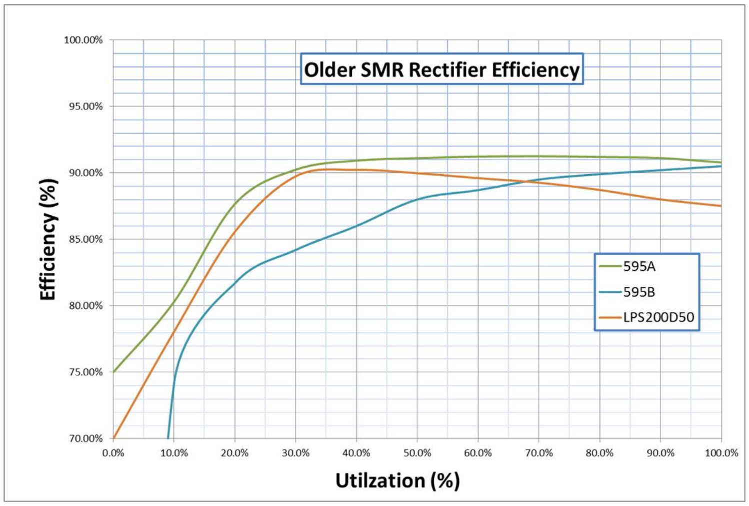

Figure 3 – Older SMR Efficiencies

2.3. Advanced Switch Mode Rectifiers

Today's state of the art SMRs can achieve efficiencies very close to 97%, and the curve of efficiency vs utilization (% load) is significantly flatter, achieving high efficiencies even at low utilizations.

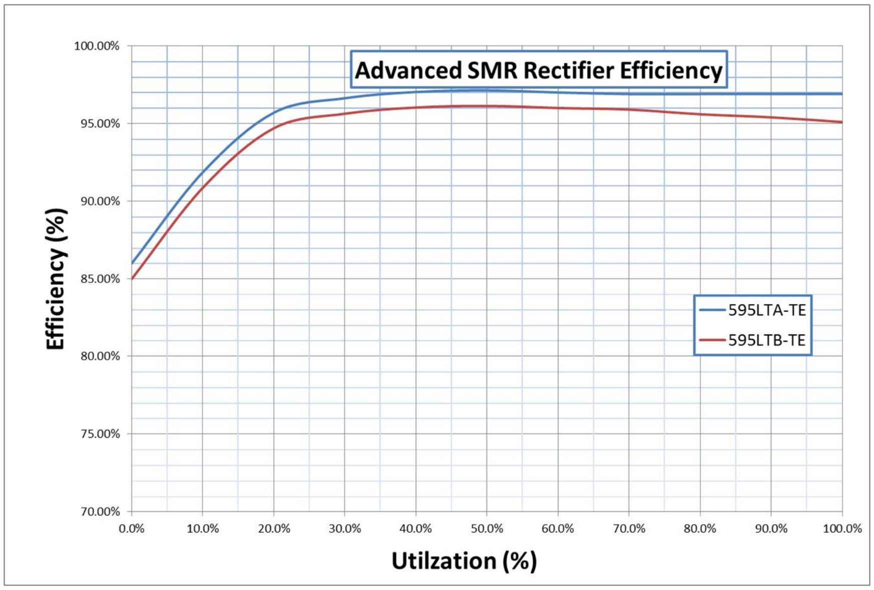

Figure 4 – Advanced SMR Efficiencies

Figure 5 illustrates a direct comparison of Advanced SMR, older generation SMRs and Ferro Resonant Rectifier efficiency performance

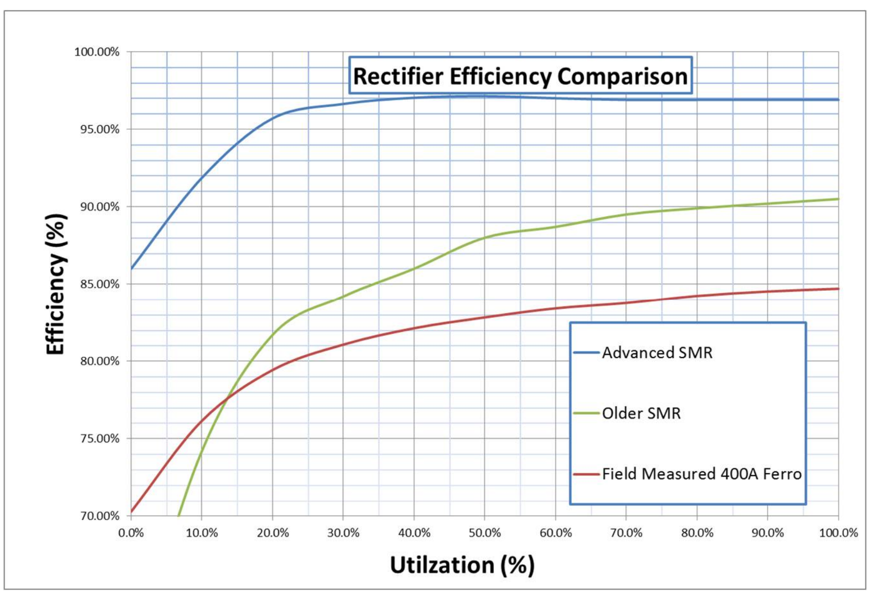

Figure 5 –Rectifier Efficiency Comparison

2.4. Potential Savings

The difference between actual efficiency and 100% represents a direct energy loss, and this energy loss is in the form of heat. In an air-conditioned building this is an additional load on the building cooling services, so any improvement in efficiency also yields a savings in the HVAC load, as well as direct input power savings for a given telecom load.

The spreadsheet shown in Figure 6 was developed to estimate savings based on efficiency improvements of rectifiers in a total system environment, including savings resulting from HVAC load decrease. The spreadsheet computes system efficiency from the actual load on the power plant, taking into account the actual efficiency curve of the rectifier model used in both the old (legacy) plant and the upgraded one. The upgrade process can also take advantage of the opportunity to "right size" the power plant to achieve optimal performance, since we have found in practice that many legacy power plants are underutilized, leading to additional inefficiencies.

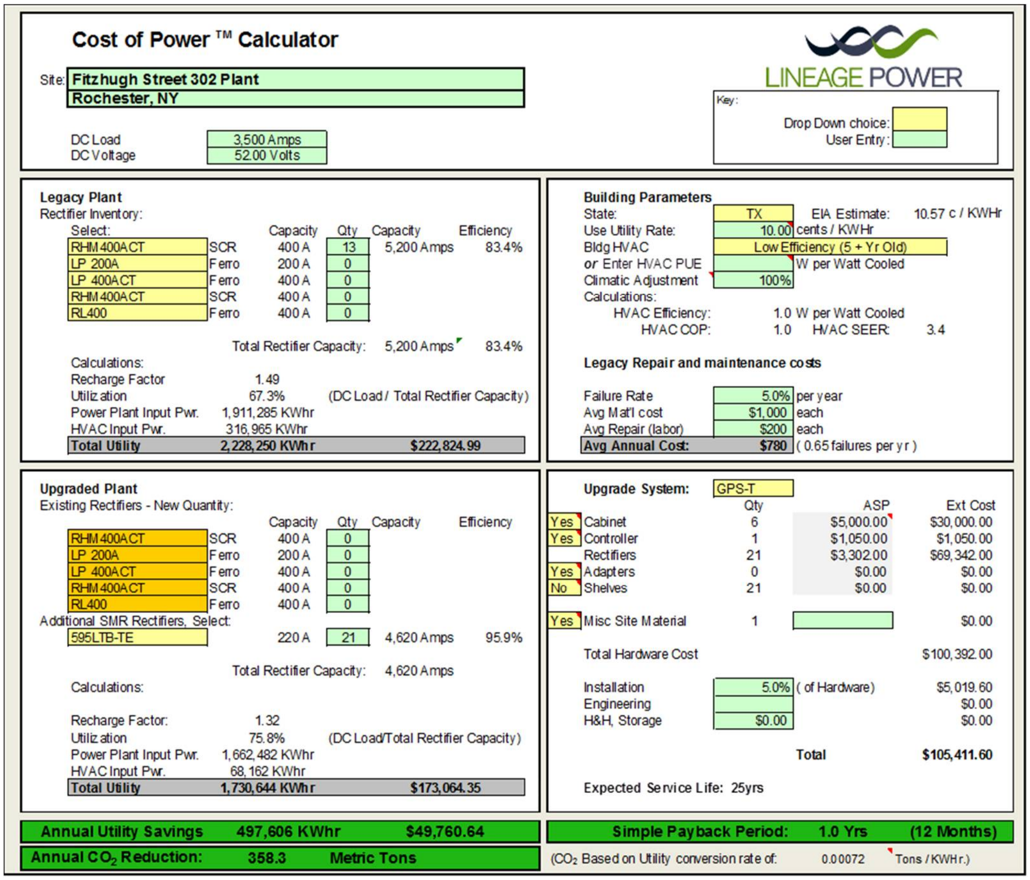

Figure 6 – Calculation of Savings

GE has found that, based on this model, a good rule of thumb for savings (based on a $0.10/kWh utility rate) is that you can expect ***$1 per year savings for each 1% efficiency improvement and 1 amp of DC load***. For example, if the efficiency of a power plant with a 1,000 amp load is increased by 5% you can expect approximately $5,000 annually in utility savings. For regions with higher utility rates the savings would be proportionally higher.

3. Upgrade or Replace?

If a legacy power plant is due for upgrade, operators are faced with a choice, usually between "do it now" or "put it off". When a power plant is replaced, usually with a more modern one offering higher efficiency, the replacement process is complicated and usually expensive. When a power plant serves several pieces of critical equipment it is unacceptable to power them down during the replacement process. This adds complexity and cost to the process, especially when the power plant feeds many pieces of load equipment. The installation and cut over cost can easily exceed the actual cost of the new power plant in a system with critical loads.

Anything that can be done to improve the efficiency of a power plant without having to replace it can make the process much simpler and dramatically less expensive.

As we have seen, the latest high efficiency rectifiers are significantly smaller than previous generations, this reduction in size allows installation of rectifiers and power plants in locations previously not possible. It also facilitates some new power architectures not previously possible.

When looking to upgrade an existing power plant, rectifier physical compatibility, while desirable, is too restrictive on new designs to be practical or economical. It is possible however to take advantage of the smaller size in the use of rectifier "carriers" or "adapters" to enable the new, high efficiency, rectifier to be used in place of the legacy unit to be replaced.

Figure 7 – Rectifier Replacement Kits

Figure 7 illustrates two different examples of how one or two of the latest, smaller, high efficiency, rectifiers can be used to replace one of the older generation SMRs using an adapter, removing the need for system replacement.

A key ingredient to minimizing the cost and complexity of an efficiency upgrade is reusing the maximum amount of the legacy plant. This can be achieved in several ways; simplest is the direct rectifier replacement if compatibility exists, then the adapter shown above, another is an updated cabinet which is compatible with the older cabinet, or as in the following example, Ferro Rectifier. The Ferro rectifier can be easily replaced since it has only AC input and DC output connections, providing the replacement cabinet is limited to the same capacity to ensure existing cables are not overloaded. This simplifies the installation considerably since cabling does not have to be replaced.

Figure 8 – Large Ferro Recitifier replaced by RPS Cabinet with 4 SMRs

In the example shown in Figure 8, the 2 x 400A Ferro Rectifiers are replaced by a single cabinet housing 4 x 200A SMRs. The cabinet is specifically designed to be able to re-use the existing cabling. While this approach does not allow recapture of floor space it dramatically simplifies installation, resulting in much lower costs.

4. Active Rectifier Management

Active Rectifier Management (ARM) is a system controller function which allows system efficiency to be optimized when redundant capacity is reducing the overall efficiency at the system level. As we have seen, with all of the rectifier efficiency curves, the efficiency of rectifiers reduces with reduced load or utilization. When rectifier systems use redundant rectifiers and have excess capacity, the utilization can be low. When system level redundancy is used (Dual or A/B power plants) utilization will be less than 40% utilization by design. Rectifier efficiency at 40% utilization or less is considerably lower than the optimum value.

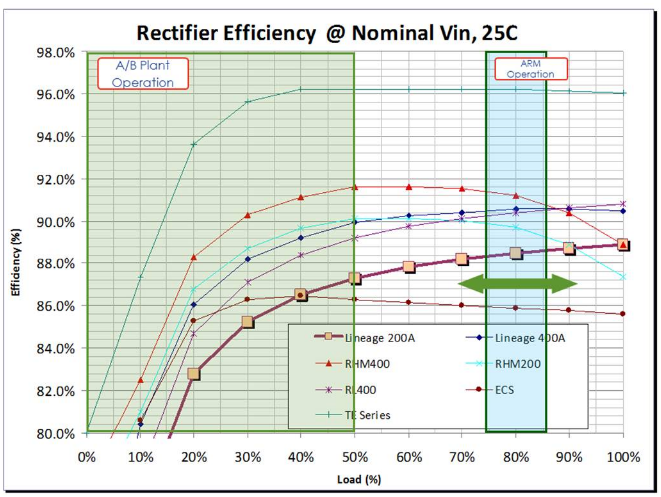

Figure 9 – Efficiency improvements on Ferro and SMR systems with ARM

To overcome this, ARM turns off rectifier capacity (placed in an “active standby” state), allowing the remaining rectifiers to operate at a higher utilization and hence higher efficiency. The effect of this can be seen in the graphs of Figure 10, the effect on the Ferro rectifier system being more pronounced than the SMR, due to the more rapid slope of the older rectifier performance curve.

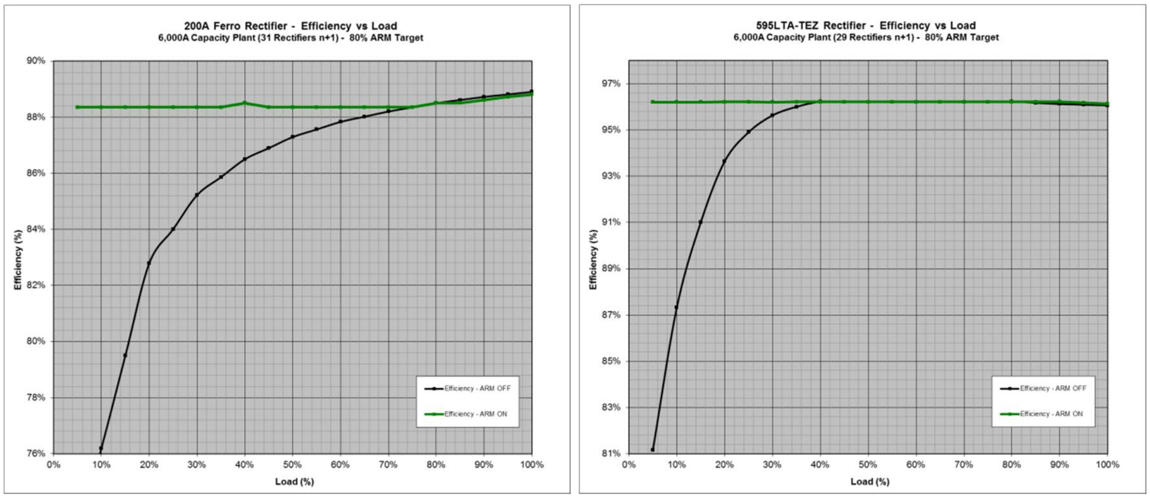

Figure 10 – Efficiency improvements on Ferro and SMR systems with ARM

5. Battery Advances

Advances in battery chemistry are also translating to significant reductions in battery size and weight. Flooded lead acid batteries providing 8 hours have traditionally been located in the basement of large switching offices because of the their size and weight.

Flooded	VRLA	Ni-Cd	Li-Ion	Na-Ni-Cl
Flooded Lead Acid	Valve Regulated Lead Acid "Sealed"	Nickel Cadmium	Lithium Ion	Sodium Nickel Chloride Battery

Figure 11 – Battery Types and Chemistries

It can be seen in Figure 12 that advanced battery chemistries are capable of providing a two to eight times reduction in both volume and weight.

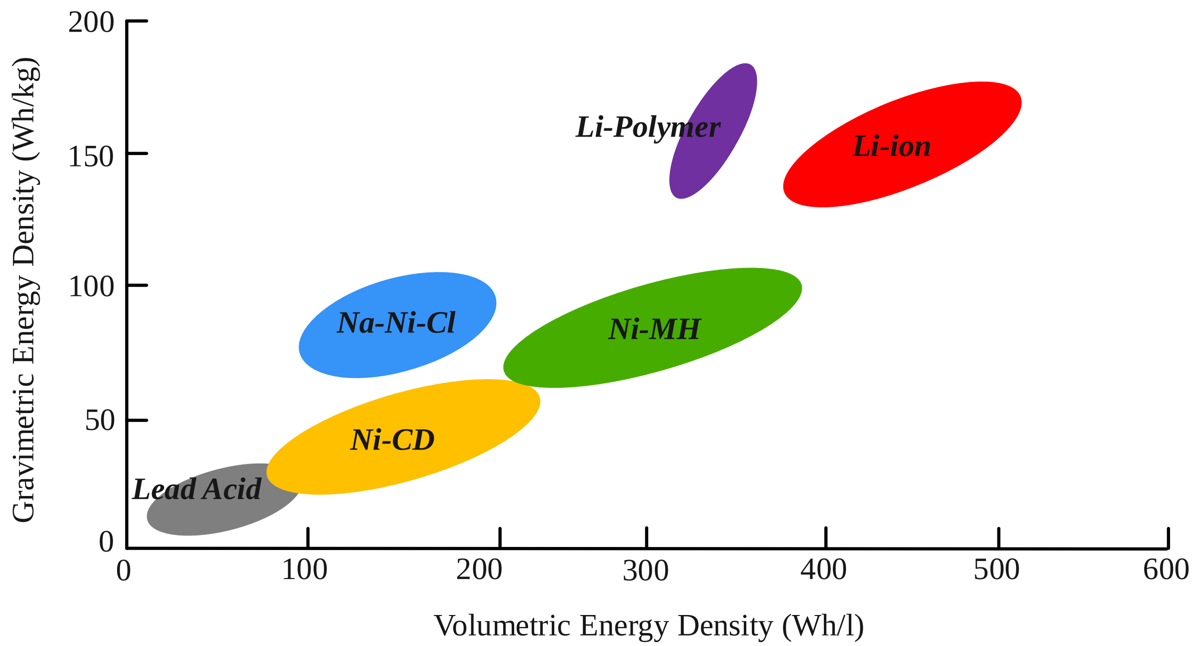

Figure 12 – Battery Density and Chemistries

With reduced reserve time requirements and advanced battery technologies, it now becomes practical to put reserve power equipment on the upper floors with a reasonable expectation that the average floor is capable of supporting it.

The choice of batteries, with the introduction of some of the more recent advances in chemistries is not obvious. The cost of the newer batteries is significantly higher than the traditional lead acid variants; however when one looks at Total Cost of Ownership (TCO) many times other advantages of the newer chemistries and potentially longer replacement intervals can offset the higher initial cost, especially when combined with savings from rectifier efficiency improvements. Unfortunately many operators do not consider TCO, preferring to evaluate opportunities purely based on initial cost. This will be the subject of a separate white paper.

6. Total Efficiency

While rectifier efficiency plays a large part in the operating cost equation, it is by no means the only area that can be improved. We must consider losses all the way from the utility service entrance panel to the load or user equipment.

6.1. AC Losses

AC losses occur between the service entrance panel and the rectifier input. This varies according to the type of system, but is typically larger for single phase and low ac voltage systems. The losses are lowest for 480V ac 3 phase systems.

Figure 13 shows example losses for some SMR based systems. Certainly, 480V ac systems are not always available, especially in low power applications, but when available it will provide significantly lower ac distribution loss.

208 vs. 480 Vac and 3-Phase vs. 1-Phase — 176A, 53V @ efficiency at 80% Load

Rectifier					AC Distribution		Total Loss	
Rectifier	Vac	Phases	Efficiency (80% Load)	Rectifier Loss	AC Dist Loss (3-Phase)		Total Loss	Efficiency Rect & AC Dist
SMR A	480	3	93.2%	634.3	354.2	3.8%	988.5	90.4%
SMR B	208	3	91.0%	839.5	522.3	5.6%	1361.8	87.3%
SMR C	208	1	92.0%	746.2	545.9	5.9%	1292.1	87.8%

3-Phase dist voltage drop taken as 1.5% per line. Line currents are phase currents * sqrt(3).

Figure 13 – AC Distribution losses for 3 phase and 1 phase systems

6.2. DC Losses

DC losses occur between the rectifier output and the input to the load equipment and include DC distribution panels and DC cabling.

Figure 14 shows one telecom operator's voltage drop budget for a large, centralized architecture DC power plant. It can be seen that the total volt drop from Rectifier to Load could be as large as 3.9V using these design standards. In a system with 6,000A of DC load, this would be equivalent to losses of 23.4kW, or 7.2%. Different operators limit the voltage drop budget to 2.0V, which would give 12kW(3.7%) losses. This reduction in losses comes at the expense of heavier gage cabling and the associated increase in capital cost required to meet the lower voltage drop requirement.

Minimizing these losses requires reducing distances between elements, using shorter and / or larger cables, and reducing the complexity of the overall system. This becomes complex and expensive to implement on an existing system with critical loads.

Smaller systems, with shorter distribution paths would be subject to significantly lower losses, but the losses are still typically significant.

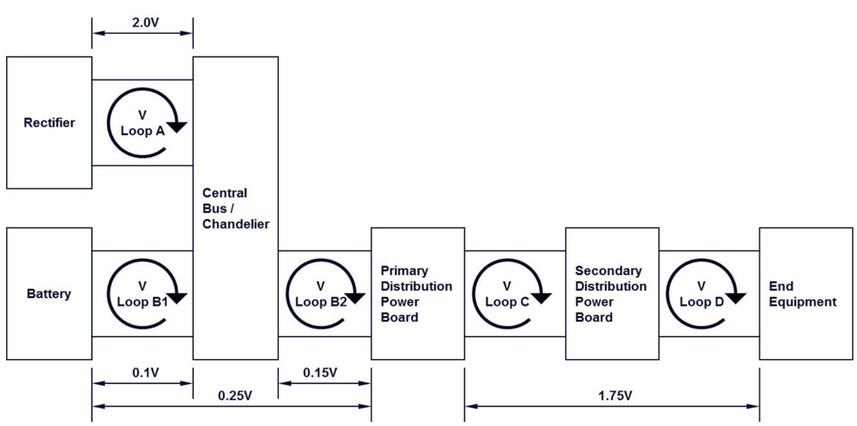

Figure 14 – Budgeted DC Distribution losses for centralized power plant systems

Clearly the losses from Ohm's law play a significant part in the total efficiency of the system. Choices in the DC power plant architecture, location and cabling are important factors to include.

7. Architectures

7.1. Centralized

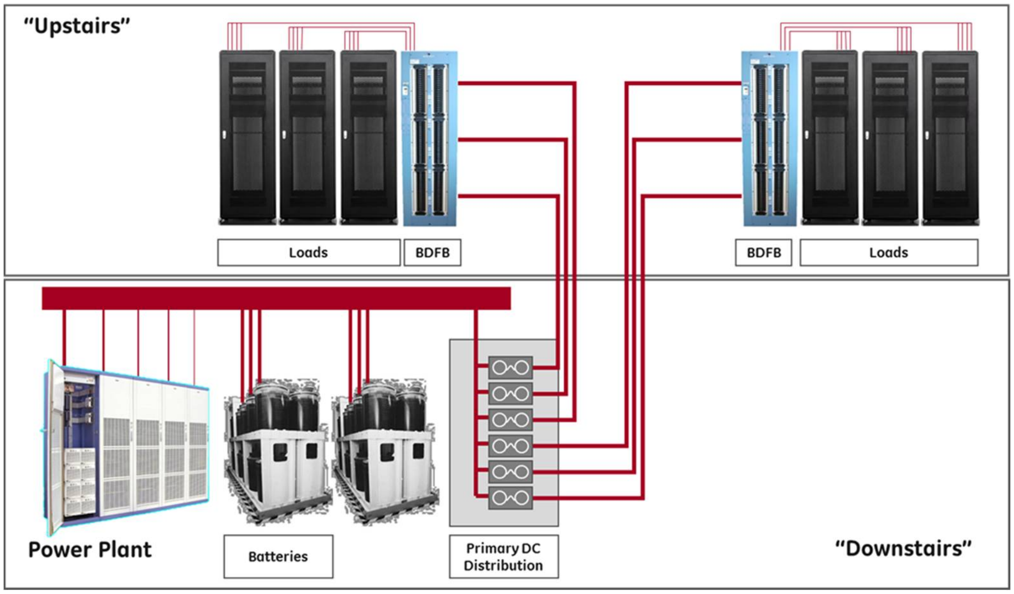

Figure 15 – Centralized Power Architecture

In centralized power plant architectures the power plant is located in a single location, frequently in the basement of large facilities. The location in the basement is primarily driven by the weight of the batteries. Primary distribution panel is typically used to distribute power to secondary panels and on to individual loads as shown in Figure 15.

7.2. Distributed

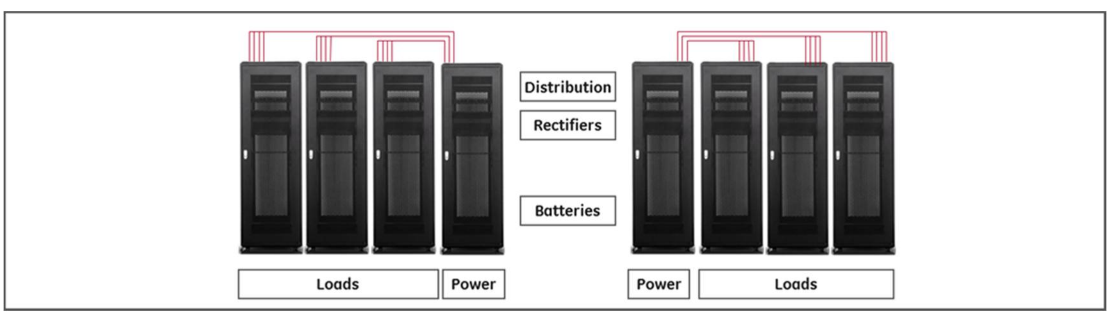

Figure 16 – Distributed Power Architecture

In distributed power architectures several smaller power plants are located throughout the building, each in proximity to the load being served, as illustrated in Figure 16. As mentioned previously, the reduction in rectifier size with the newer units, and alternate battery chemistries, have enabled installation of power in locations not previously possible, and distributed architectures take advantage of these size reductions. The ultimate distributed power architecture can include actually placing the power plant inside each load cabinet, as shown in Figure 17.

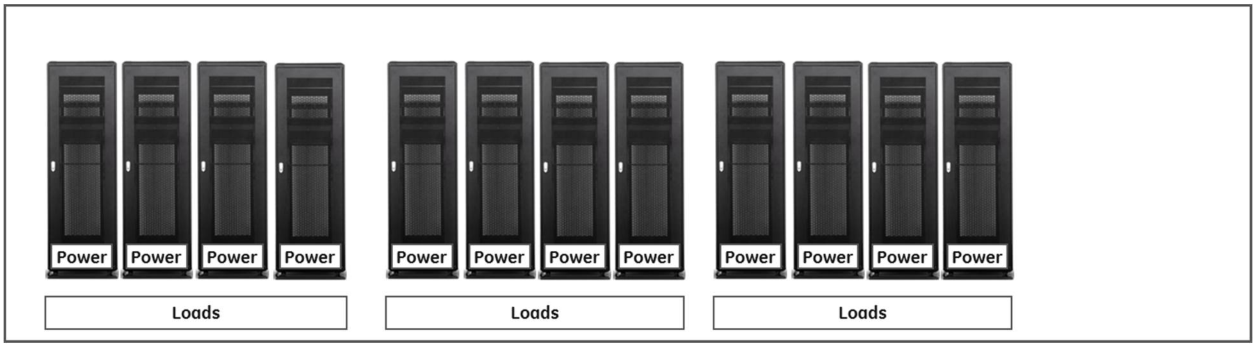

Figure 17 – Distributed Power Architecture

7.3. Advantages of Distributed Power Architectures

Efficiency **-** By moving power conversion closer to the load, DC distribution losses are dramatically reduced. They are replaced by much smaller AC losses, due to the higher voltage and lower current of the AC distribution system. This improves the "end-to-end" efficiency and will result in a reduction in a facility's OpEx.

Higher Voltage AC **-** The use of higher AC voltages, when available, reduces the losses in the AC distribution portion of the system. 3 phase, 480Vac yields the lowest losses and coincidentally results in the highest efficiency rectifiers.

Copper Cable **-** The reduced distance that the lower DC voltage has to travel requires many times smaller conductors carrying current over much reduced distances, resulting in enormous reductions in CapEx required to purchase and install the copper cable. The use of higher voltage AC distribution also reduces the size of the conductors required for the AC side.

Voltage Budget **-** By placing the power plant closer to the load the opportunity exists to reduce the budgeted DC voltage drop, which improves efficiency as well as giving better battery reserve utilization.

Cooling – Reductions in copper losses and improvements in conversion efficiency will reduce wasted energy and further reduce OpEx by reducing the load on the HVAC system.

Flexible Energy Reserve **-** By distributing the power conversion equipment to feed a portion of the load equipment, it is possible to provision reserve time appropriate to that load equipment. This means that if one load needs a longer reserve time, it can be provisioned without encumbering the entire facility with the cost of the longer reserve time. The reserve time can be matched to the load in appropriate increments.

Reliability – Grouping smaller loads with smaller power plants decreases the size of a given failure group, due to power issues, resulting in an overall increase in reliability.

Scalability – Power equipment is added incrementally along with load equipment, minimizing initial power equipment and installation costs (CapEx).

8. Renewable Sources

8.1. The Telecom DC Power Plant (DC UPS)

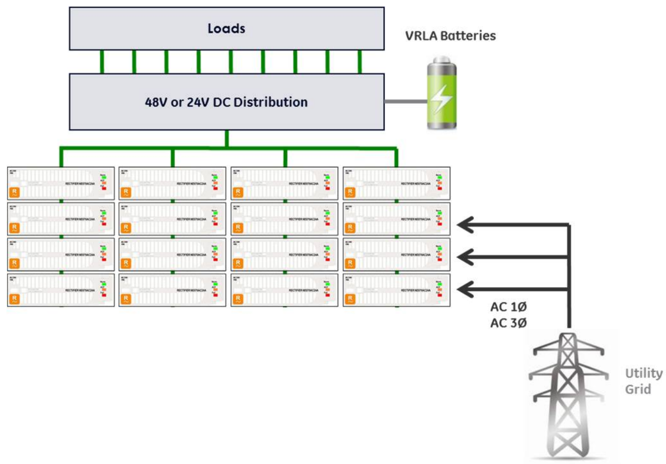

Figure 18 - Traditional Telecom DC UPS

In the traditional telecom industry DC power plant, shown in Figure 18 energy from the utility source is converted by rectifiers to DC at the standard 48V or 24V DC to keep batteries charged. This DC power is then fed through a distribution unit, equipped with current limiting fuses or breakers to the telecom loads.

In case of utility power failure the batteries supply the load current without interruption. This basic system has been used since the invention of the telephone.

8.2. ECO Priority DC UPS

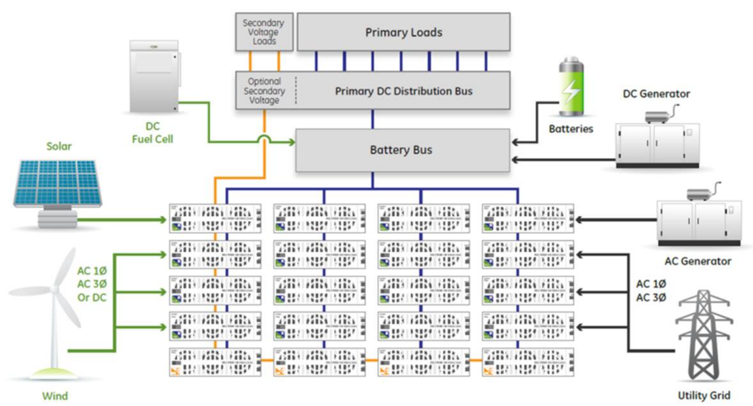

Figure 19 - ECO Priority DC UPS

In the ECO Priority implementation of the DC UPS, shown in Figure 19, the basic rectifier is able to accept energy from different sources and combine their energy on a common DC bus. Renewable energy sources are inherently intermittent, so when they are available it is important to maximize their output, and when they are not available we must seamlessly transition to other sources or stored energy reserves. Traditional telecom powering architectures based on a DC bus structure provide a reliable way of aggregating multiple energy sources and providing proven, reliable transitions between sources and reserve energy storage media.

ECO Priority source provides the most efficient power conversion scenario by minimizing the number of conversion steps between source and load and maximizing the efficiency of each step.

For example, traditional solar panel DC output is either processed by inverters or micro-inverters to an interim AC voltage, or processed by a specialized DC/DC converter. While the first traditional method introduces 2 conversion steps, and is inherently less efficient, both methods introduce new electronic equipment that must be sourced, spared, maintained, repaired and stocked.

Conversion of solar power directly to the DC bus voltage required by load equipment minimizes conversion steps and losses, as well as providing a very convenient and simple power aggregation bus at the DC level.

Key characteristics of this approach are:

1) The user only has to stock and spare a single part number, or SKU, for rectifiers that operate from any source, commercial, fossil fueled or renewable.

2) Power from renewable sources is prioritized for first use automatically by the rectifier when it recognizes that it is operating from a sustainable source of power

3) Renewable sources are integrated in with a fully functioning battery plant with no special integration skills required on the part of the facility designer or installer.

For the service provider who must maintain the network over time, avoidance of a disparate set of equipment promotes sustainability of the network and ultimately quality of service.

ECO Priority source operation is compatible with many different energy sources, including solar, wind, AC and DC generators, fuel cells, single phase, 3 phase and low frequency AC.

8.3. Applications

8.3.1. Off Grid

In an off grid application, as the name suggests, the utility grid is either not present or inaccessible. Providing access to the grid is typically prohibitively expensive. In these applications it is necessary to provide alternative energy source(s). These may be solar, wind, fossil fuel generators etc.

The ECO Priority architecture shown in Figure 19 is ideally suited to these applications, having the ability to combine multiple sources into a single integrated system.

8.3.2. Grid Supplement

When the utility grid is available, it may be desirable to supplement it with renewable energy sources to reduce the utility power cost, or improve on its availability. Again, a simplified version of the ECO

Priority architecture shown in Figure 19 is ideally suited to this purpose. It can be used as a complete power solution in a new installation, or as a supplement to an existing system.

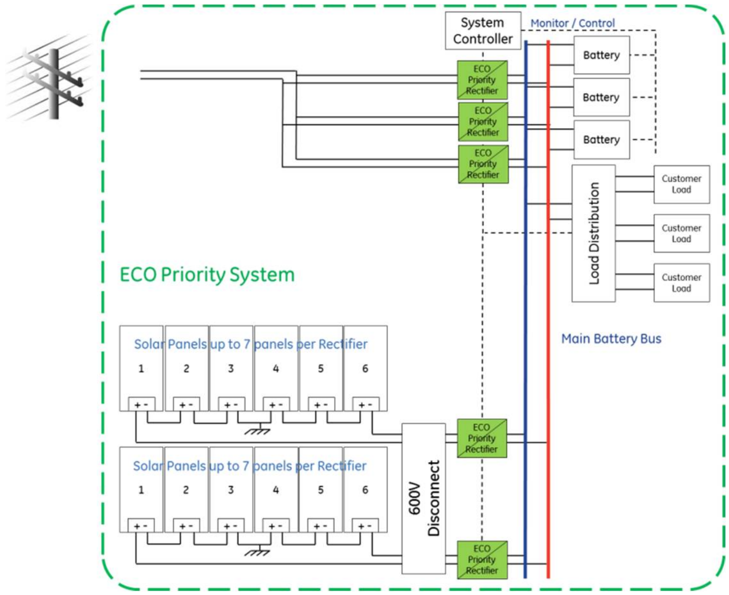

Figure 20 – ECO Priority Power Plant with Solar and Grid inputs

The illustration in Figure 20 shows an ECO Priority power plant with both utility and solar inputs. Both input sets are representative only, and can be expanded as required, by plugging in additional rectifiers.

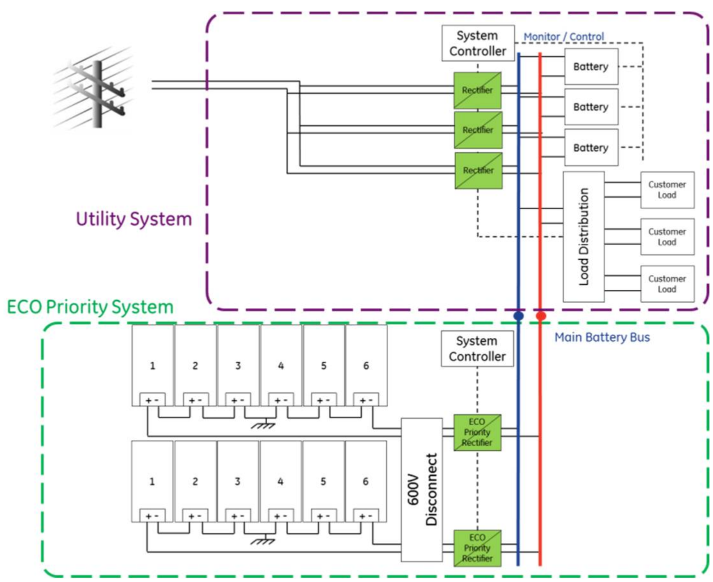

Figure 21 – ECO Priority Power Plant supplementing an existing Utility Plant

When used with an existing system, to supplement existing power sources, the ECO Priority system is simply connected to the DC bus of the utility system, as shown in Figure 21, without need for any additional interface, making it compatible with virtually all manufacturers' DC power systems.

8.4. Solar Capacity Calculations

Engineering the right scope and level of solar power seems like a simple calculation. Assuming an average power load for a one kilowatt (kW) off grid site, and with a goal of powering the entire load, you might expect to install at least 1,000 Watts (W) of solar panel capacity.

Yet, given an optimum solar generation period of five hours a day (location dependent), you need four to five times the number of solar panels to meet your power needs – additional solar power is required to charge batteries during the day for discharge at night. Factor in local weather trends – for both cloudy days and ambient temperature – and ***actual solar panel capacity required will be at least 5 x the load capacity***.

In the case of supplementing grid power, the scenario is simpler; however much power is available during solar activity is going to offset or reduce the utility load, up to, but not exceeding, the actual load requirements. If you wish to exceed the load requirements to offset some night time grid power, then cyclic energy storage must be included and the effect of cycling battery capacity must be considered.

In a recent proposal that was done for a cable operator in New York as a "grid supplemental" operation, it was calculated that a 7,500 square foot roof-top solar array would provide an average of 1,600A of 48VDC power to help offset utility power costs during daylight hours.

8.5. Battery Considerations

Most lead acid batteries are not designed for a daily depletion and recharge; most manufacturers recommend cycling discharge level of only 20-30 percent to preserve the life and performance of the battery. At 30 percent discharge capacity, a solar powered installation needs ***at least three times the expected battery capacity*** to provide the power during night time periods.

GE Energy Upgrade Scenarios - Hybrid Solar / Generator operation

Location:	Denver Co area			
Solar:	5.22		Lo Temp	-7 °C
Required Autonomy:	12	Hours	Pnls/Strg	6
Cloudy days per year:	0			
Solar Panels:	CS 300	300 W Canadian Solar		20.67 sq ft
Scenario #:	***3***		Genset & Solar?	Yes

Scenario #		Load			Solar Panels								VRLA Battery					Daily	Daily	Est. Battery Life		Generator			Total Rects
		DC	AC	Total	Optimal Calculated				Over-Ride Calculated				169 Ahr			Gel	Autonomy	# Cycles	DOD	Gel		5.0 KW			
		Watts	Watts	DC Watts	Rated Watts	Max Rating	# Panels	Calc # Rect	O-Ride Panels	Area Sq Ft	O-Ride #Rect	Act Watts	Calc Ahr	Calc Strings	O-Ride Strings	Actual AH	(Hrs to 80% DOD)			Cycles	Yrs	Run %	Hrs/yr	Rects	
3	**Denver, CO**	1,000	0	1,000	6,530	300 W	**24**	**4**		496	4	5,760	1,159	7		1,183	51	1.00	30%	1,880	5.15	0%	0	2	6

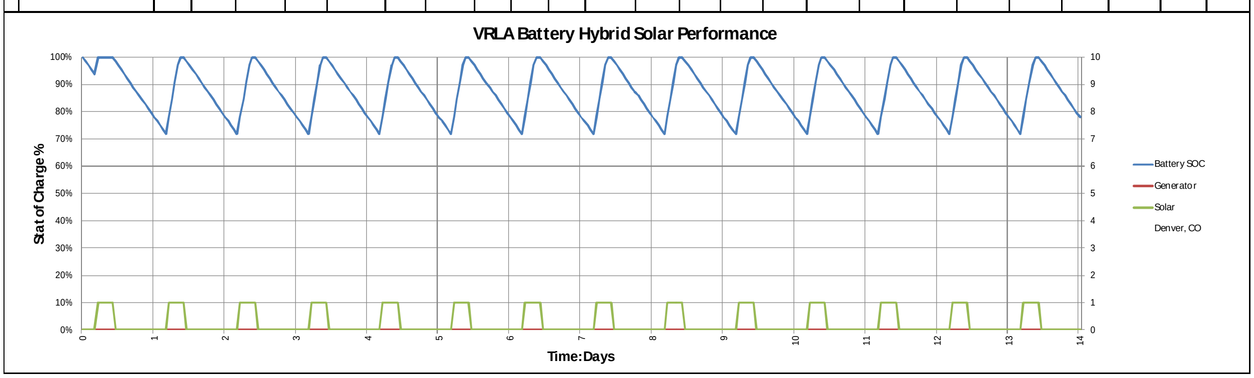

Figure 22 - Battery State of Charge and Source Utilization Plot – VRLA batteries

Figure 22 shows the battery state of charge plot over a 14 day period, for our 1kW example, in a Denver, CO. location. 24 x 300W solar panels will be required, and 1,159Ahr of battery capacity. In this location, due to the low temperatures in winter time, 24 panels can be configured as 4 strings of 6 panels (connected in series), with a total area of 496 sq. ft. The batteries can be seen to cycle on a daily basis.

Due to the large size, and not insignificant cost, of solar panels, many operators elect to provision reduced amounts of solar capacity and supplement with fossil fueled generators or fuel cells. This represents a tradeoff between capital expense (solar panels) and operating expense (periodic re-fuelling cost). Many factors, including location, fuel consumption, fuel cost and accessibility factor into this evaluation.

Figure 23 shows how a reduced solar capacity (12 panels instead of the requisite 24 panels) results in the inability to completely recharge the batteries after a nights discharge, triggering the generator to run periodically.

Scenario #		Load			Solar Panels								VRLA Battery					Daily	Daily	Est. Battery Life		Generator			Total Rects
		DC	AC	Total	Optimal Calculated				Over-Ride Calculated				169 Ahr			Gel	Autonomy	# Cycles	DOD	Gel		5.0 KW			
		Watts	Watts	DC Watts	Rated Watts	Max Rating	# Panels	Calc # Rect	O-Ride Panels	Area Sq Ft	O-Ride #Rect	Act Watts	Calc Ahr	Calc Strings	O-Ride Strings	Actual AH	(Hrs to 80% DOD)			Cycles	Yrs	Run %	Hrs/yr	Rects	
4	**Denver, CO**	1,000	0	1,000	6,530	300 W	**24**	**4**	**12**	248	2	2,880	1,159	7		1,183	51	0.50	30%	1,880	10.30	13%	1,115	2	4

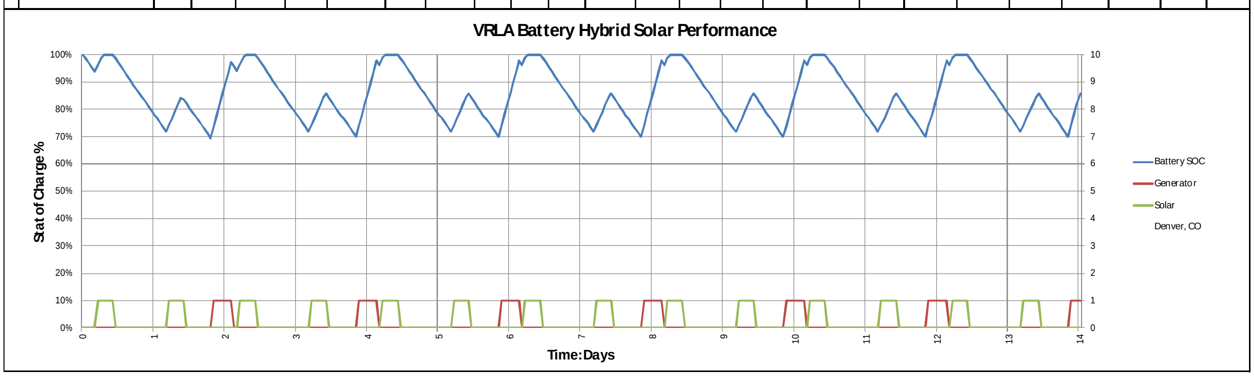

Figure 23 – Reduced Solar Capacity Source Utilization Plot – VRLA batteries

8.6. Battery Chemistry

Battery characteristics and performance affect the tradeoffs and choices made in optimizing a system for different applications. New sodium nickel chloride battery technology is changing that charge-discharge dynamic, allowing discharges of 80 percent of the battery's power between recharge cycles. These batteries maintain a high-energy output throughout more than 5,000 deep-discharge cycles. Figure 25 illustrates the performance of sodium nickel chloride batteries in the same example as Figure 22, the 80% discharge parameter allows battery capacity to be reduced to 435Ahr instead of the 1,159Ahr of VRLA battery.

Figure 24 – Sodium Nickel Chloride Battery

Scenario #		Load			Solar Panels								Durathon Battery					Daily	Daily	Est. Battery Life		Generator			Total Rects
		DC	AC	Total	Optimal Calculated				Over-Ride Calculated				256 Ahr			Durathon	Autonomy	# Cycles	DOD	Durathon		5.0 KW			
		Watts	Watts	DC Watts	Rated Watts	Max Rating	# Panels	Calc # Rect	O-Ride Panels	Area Sq Ft	O-Ride #Rect	Act Watts	Calc Ahr	Calc Strings	O-Ride Strings	Actual AH	(Hrs to 80% DOD)			Cycles	Yrs	Run %	Hrs/yr	Rects	
3	**Denver, CO**	1,000	0	1,000	6,530	300 W	24	4		0	4	5,760	435	2		512	22	1.00	80%	5,000	13.70	0%	0	2	6

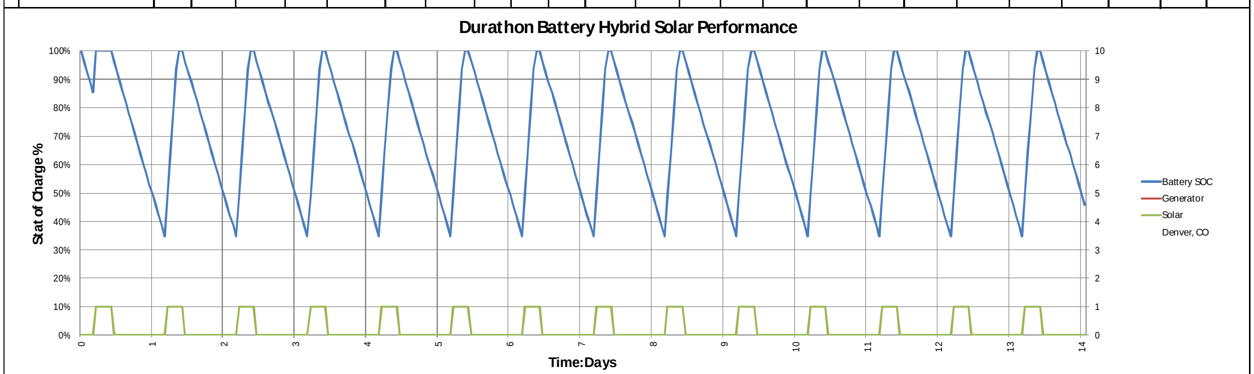

Figure 25 - Battery State of Charge and Source Utilization Plot – Sodium batteries

In addition to its cycling ability, sodium nickel chloride batteries operate with an internal temperature of 300°C, so cooling the batteries is not required. Operating between -40°C and +65°C, battery cooling and heating energy can be removed from the site's power budget.

Operational efficiencies and cost savings are also created with remote monitoring. Real-time visibility and reports on conditions such as generator runtime, solar panel output, rectifier history and discharge status, give operators insight into operations while reducing maintenance truck rolls to the facility.

8.7. Practical Tradeoffs

A typical solar panel can produce 200-300Watts from a 21 square foot panel. In practice, a 300 watt panel can support less than 60 watts for 24 hours a day. This leads to approximately 500 square feet of solar array per kilowatt of load. While this may not seem like much, when space is being leased by the square foot, it cannot be disregarded; indeed, in some locations it may simply be unavailable.

Cost of solar panels, while gradually decreasing, is still high enough that it must factor in to decisions. Payback considerations will be significantly affected by high cost of solar panels, installation and power processing equipment. Fortunately there are significant utility incentives and government subsidies available for alternate energy installations, these vary from location to location, so each installation needs to be evaluated on an individual basis.

As a result of these and other factors, the decision is often made to trade some of the cost of solar energy infrastructure for generator run time. Smaller solar capacity can be supplemented with generator run time, as illustrated in Figure 23.

Similar considerations arise when calculating and provisioning battery capacity. The physical size and cost of large battery strings can become prohibitive, so again, a tradeoff is available. Smaller batteries require more frequent and less efficient generator runs. The minimum size of battery however needs to be dictated by the amount of solar energy available for storage for night time use. If storage capacity is not available the solar energy maybe wasted.

In the case of sodium nickel batteries, the additional cost of batteries is reduced by the need for less capacity and also by the removal of the need to cool batteries. In an off grid scenario the energy required to run air-conditioners cannot be underestimated, it must also come from the local energy sources and significantly affects the capacity of local energy sources needed.

It is important when contemplating an alternative energy powered project that the objectives are clearly defined at the outset, since these will determine the direction that the various possible tradeoffs take.

Figure 26 illustrates some of the competing objectives and parameters that can be the subject of operational tradeoffs. This list is not intended to be exhaustive.

Off Grid	Grid Supplement	Multi Source	Peak Shaving
Solar Only	Location / Site Limitations	Geographical Location	Grid Demand Response
Solar Capacity	Solar and Grid	Solar, Grid, Generator	Site Autonomy Time
Solar, Wind and other sources	Minimize Ongoing Opex	Minimize Generator Run Time	Minimize Initial CapEx

Figure 26 – Competing Objectives and Tradeoff Drivers

8.8. Tools - What if?

Figure 22, Figure 23 and Figure 25 were generated using a "what if" tool based on fundamental energy equations in an excel spreadsheet. The user is able to plot the battery state of charge (SoC) over a period of time to determine how the system performs with different capacity configurations. The user can very easily repeat with different solar, battery and generator configurations to determine optimum performance, or the optimum configuration that meets other constraints, such as refueling cost and solar panel space limitations. For example Figure 23 was plotted for a configuration that did not have sufficient solar capacity, and hence the generator is needed to run for several hours per day. Figure 25 shows the exact same system with an equivalent capacity of Sodium Batteries substituted for the VRLA battery used in Figure 22. Using the deeper discharge capacity of the battery changes the SoC characteristic dramatically.

Use of this, and other commercially available tools, allows the rapid evaluation of different configurations and the impacts of the previously mentioned tradeoffs.

9. Conclusion

The first half of this paper examined advances in rectifier technology, leading to significant improvements in efficiency. Upgrading existing power plants by use of modern, high efficiency switch mode rectifiers can save OpEx by reducing power consumption. The ability to replace just the rectifiers in an already installed power plant can dramatically reduce the cost of an upgrade, since much of the cost of power plant replacement is in the installation cost. The use of innovative rectifier “carriers” or “adapters” is one way to simplify upgrades and minimize costs.

Improvements in size of rectifiers have also enabled the development of distributed power architectures that can improve overall power efficiency and can dramatically reduce OpEx.

In the second half of the paper we examined alternative energy sources and how to integrate them in to power systems to power practical sites. There are many considerations and options that involve user decisions and tradeoffs. These tradeoffs can be compared using some of the “what if” tools and options illustrated.

Solar energy can be used to power a site, or supplement utility power, reducing the OpEx dramatically. Other forms of alternate energy, such as wind and alternative fuel generators can be used in addition to solar energy, but solar is, in our experience, the most popular source at present. The cost of solar energy is still relatively high when compared to the $0.1 / kWhr utility power that much of the country enjoys, but incentives and subsidies can make it a viable alternative in many cases, especially regions with much higher utility costs.

Depending on the objectives of an alternative energy system, many tradeoffs must be considered and resolved. Each site will have its own unique set of constraints and objectives, making the tradeoffs specific to that site. To this end, a tool that can compare performance and cost of different configurations can be invaluable.

A flexible architecture, such as ECO Priority, that can combine more than one source of energy, using common rectifier equipment, can make powering a site from renewable energy cost effective and affordable.

10. Abbreviations

ARM	Active Rectifier Management
CapEx	Capital Expenditure
OpEx	Operational Expense
SMR	Switch Mode Rectifier
SCTE	Society of Cable Telecommunications Engineers
UPS	Uninterruptible Power Supply