LIFE CYCLE COST COMPARISONS of VRLAs to ALTERNATIVES in HOT OUTDOOR ENVIRONMENTS

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ABSTRACT

For facilities-based telecommunications industries, like the wireline telephone companies, the cable TV companies, etc., there are tens of thousands of outdoor electronic equipment cabinets (equipped with batteries) in "hot" environments. These batteries are mostly gel or AGM VRLAs. It is a well-known fact that all lead-acid batteries lose life rapidly when exposed to heat. Because of this, VRLA batteries that might get 7-10 years of life in a controlled environment often only get 1-3 years of life in uncontrolled environments where summer temperatures often exceed 100 degrees F. There are several alternatives to lengthen the life of the backup power system already on the market, and several others in development. They can generally be classed into one of 3 categories:

1. Cooling VRLAs
2. Replacing the VRLAs with other battery types or flywheels
3. Providing other primary or standby AC or DC sources in order to reduce battery reserve

The alternatives include the following:

- CoolCells™
- Thermo-Electrics
- Buried enclosures
- Air-conditioning
- Phase-change materials
- Refrigerant driven "cold plates"
- Nickel-Cadmium batteries
- Lithium-ion batteries
- Lithium-polymer batteries
- Flywheels
- AC or DC fuel cells
- Engine-alternators or DC generators
- Microturbines

All of the alternatives have a higher initial cost than simply installing VRLA batteries in an uncontrolled environment. However, because VRLA batteries will have to be replaced more often, and receive more maintenance than some of the technologies, some of the alternatives listed above can have an equivalent cost to VRLAs in as little as 4 years. (And some won't pay for themselves for more than 20 years.) The payback interval is determined by doing a Net Present Value analysis. A sample graph of one for a flywheel is shown in Figure 1.

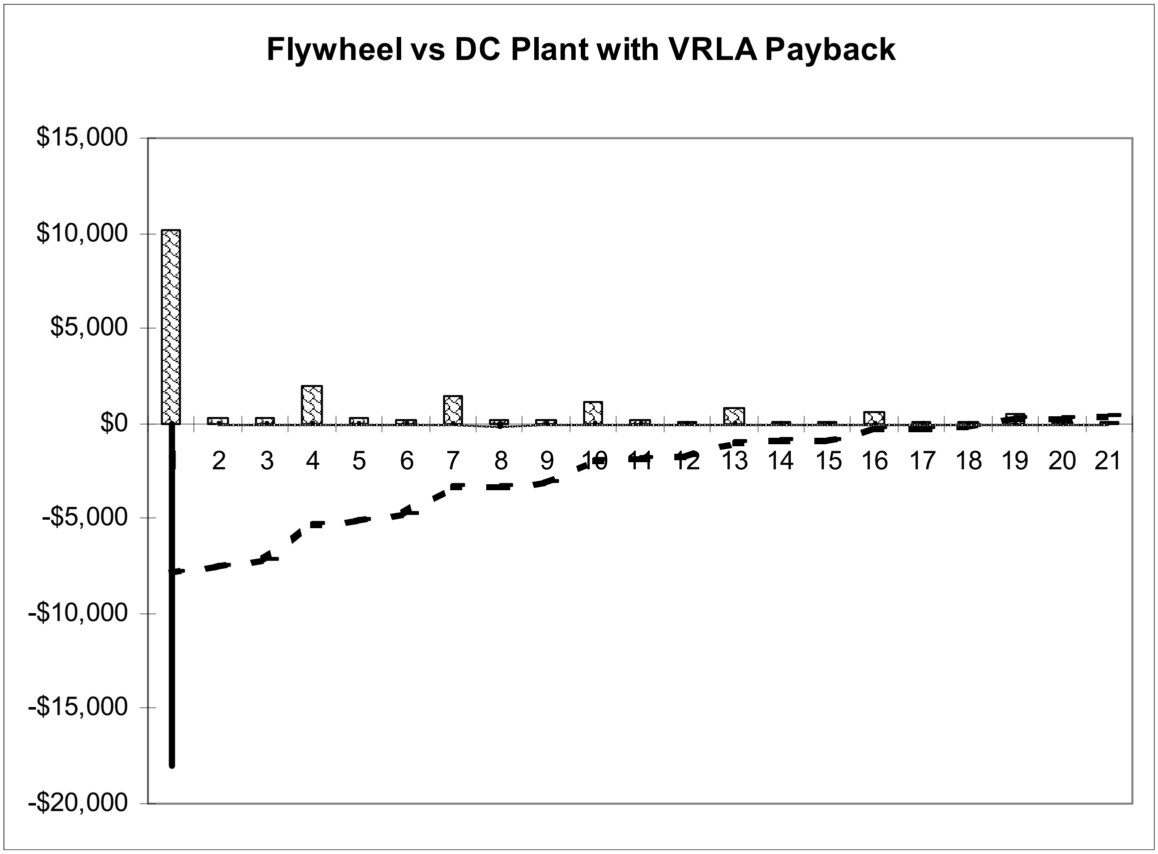

Figure 1
Sample NPV Analysis for Flywheels vs. DC Plant in a Hot Desert Environment

Depending on the circumstances (amount of batteries used today, battery life in the climate they're in, maintenance done, etc.), the payback for each option will vary by company, industry, and climate (among other factors). However, for any of the alternatives, an NPV analysis can be done. The payback period must then be "sold" to the Finance department as good business. Then an alternative technology can be used. Several companies have adopted some of the solutions mentioned.

This paper covers the basic descriptions of the alternatives, their pros and cons, the basics of performing an NPV analysis, and some sample results for one industry in one particular climate. It also discusses why the electric vehicle (EV) industry may play an important role in determining the best alternatives to VRLA batteries for the future.

INTRODUCTION AND BACKGROUND

As mentioned in the abstract, there are tens of thousands of cabinets with VRLA batteries in hot environments. An example of one type of these cabinets used for telecommunications is shown in Figure 2. Figure 3 shows batteries inside of a similar cabinet. (Some batteries are in the electronics compartment, and others are underneath or to the side of the electronics in a separate chamber.)

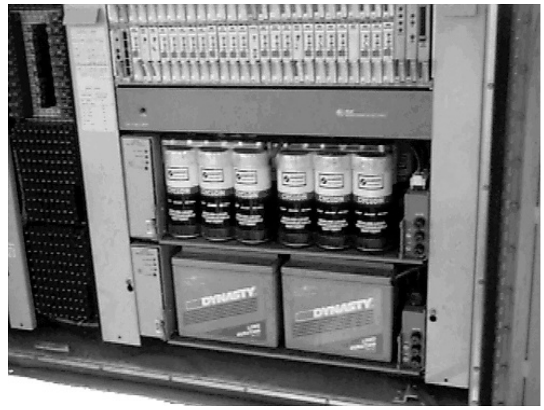

Figure 2
Avaya 80D Bulk Power DLC Telephony Cabinet

Figure 3
Batteries inside a Distributed Power 80D Cabinet

As is well-known, VRLA batteries, especially in these types of environments, have the following problems (among others):

- Thermal Runaway
- Short Life: 2-3 yrs or less in desert uncontrolled environment cabinets
- Heavy (Not as energy dense as some batteries)
- Recycling Issues
- Gassing
- Yearly (or more often) maintenance to ensure best reliability

Their great advantage is that they are relatively inexpensive. (The section on how batteries and vehicles are related will explain part of the reason for this relatively low first cost.) They are also a proven and well-known technology.

Figure 4 shows what happens to a cabinet where the battery area is not ventilated to outside air. The picture is enough to scare anyone, but one of the many reasons alternatives to VRLAs are being sought.

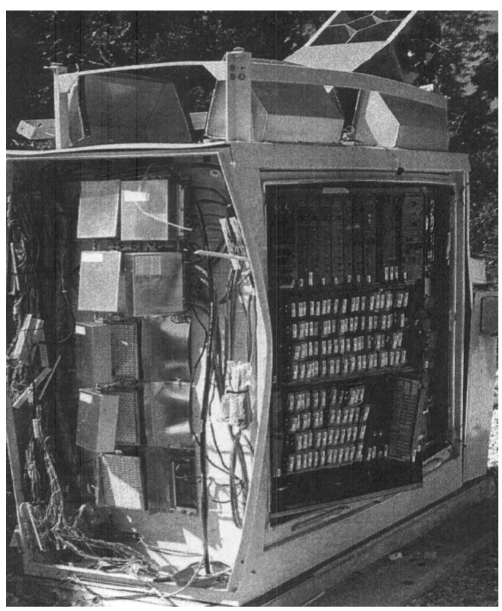

Figure 4
A Telephony DLC Cabinet with an Unventilated Battery Chamber after Thermal Runaway and Explosion

THE ALTERNATIVES

Table 1
Descriptions of the Alternatives for/to VRLAs in a Hot Outdoor Environment

Alternative	Brief Description
Alternatives for Cooling VRLAs	
CoolCell™	This patented product uses the natural thermal circulation of water and the concept of night sky black body radiation to keep the batteries typically below 80 degrees F at all times.
Thermo-Electrics	Several cabinet manufacturers use these common semiconductors that heat on one side and cool on the other when DC current is passed through. A fan then blows air over the cool side and into the cabinet.
Burial	This idea simply involves burying the batteries in a vault far enough below grade to get a more constant (and hopefully lower) temperature.
Air-Condition	Uses conventional refrigerant, compressors, fans, etc.
Phase-Change Materials	These materials change from solid to liquid (or vice-versa) at certain temperatures. The energy consumed (latent heat of fusion) by this phase-change process significantly shaves the peaks, both high and low, off of ambient temperature changes. Although these materials don't allow the battery to get as cool, they don't allow it to get as hot. The theory (still being tested) is that because batteries lose more life at temperatures above 77 degrees F than they gain for corresponding temperatures below 77 degrees F, there will be increased battery life in certain climates.
"Cool" Plate	This technology uses refrigerant pumped through a plate placed underneath the batteries. It is currently being refined, reviewed, and tested.
Alternatives to Replace VRLAs	
Ni-Cads	This technology has been around for a long time, and only loses 20% as much life as VRLA batteries do at equivalent high temperatures.
Li-ion batteries	For most of the last decade, these have been the most energy-dense choice for portable backup applications, e.g., cell phones, laptops, etc. They are finally being scaled up to sizes large enough to be used in outdoor cabinets.
Li-polymer batteries	These are being developed and tested for the electric vehicle, electric utility, and telecommunications markets. In contrast to VRLAs, they love the heat. In fact, they only work at higher temperatures, so they require internal heaters.
Flywheels	The flywheels being tested for backup use in outdoor cabinet applications use a light but strong carbon-fiber composite wheel, are contained in a strong vacuum (hardly any friction), and are supported on magnetic levitation bearings (low friction). Because the flywheel produces AC, it must be equipped with a built-in rectifier. With a few more electronics, the flywheel and its electronics can replace not only the batteries, but the rectifiers as well.
Primary or Standby Source Alternatives to Allow the Reduction of Backup Battery Capacity	
AC output Fuel Cells	Fuel Cells usually use Hydrogen, which can be reformed from natural gas, LPG, or other fuel sources, and Oxygen from the air as fuel, and produce electrons, water, and heat. AC output fuel cells can be advantageous where natural-gas-produced energy is cheaper than electricity from the electric utility and/or there are AC loads that need backup.
DC output Fuel Cells	Because the natural output of a fuel cell is DC, for sites that only need DC power, this can serve as a primary or backup source, and save the cost of the inverter.
Engine-alternators	The fuels can be various, but most common for outdoor cabinets is natural gas or LPG. They are used as a standby source because in most areas, the fuel and cost of running them is not cheaper than the cost of electricity most of the time.
DC Generators	These are usually engine-alternator sets fitted with a commutator or regulator/rectifier. They would be used where only DC loads need backup.
MicroTurbines	Similar to fuel cells, these are being touted as a primary source of AC in a deregulated and maybe less reliable electric market. These are not much more than tiny jet engines.

All of the primary or standby source alternatives shown at the end of Table 1 have a startup time from a few seconds to a few minutes. So, for truly uninterruptible operations, they cannot be used as a battery replacement. However, they can be used as a primary source instead of commercial AC power, or as a standby AC source. In either of these cases, depending on regulatory rules, battery reserve could be reduced but not eliminated. Reliability studies would probably come into play in these scenarios. Figures 5 and 6 show a CoolCell™ deployment:

Figure 5
One Size of a CoolCell™ Enclosure

Figure 6
Batteries Inside a CoolCell™

PROS AND CONS OF THE ALTERNATIVES

The Introduction listed some of the major advantages and disadvantages of VRLA batteries. Table 2 lists some of the pros and cons of the alternatives. The cons include some of the maintenance. For all the alternatives that still include VRLA batteries, the same battery maintenance listed in the Introduction is still necessary.

Table 2
Pros and Cons of the Alternatives for/to VRLA Batteries in Hot Outdoor Environments

Alternative	Pros	Cons	Alternative	Pros	Cons
CoolCell™	< 85°	Water 2-3 yrs Extra cabinet One manufacturer	Burial	Slightly cooler Shaves peaks Cost reasonable	Venting Deep burial
Air-Conditioning	Very cool Cost reasonable Small space	Hi maintenance AC = $200+/yr	"Cool" Plate	Small Cost reasonable < 80°	Not ready yet Maintenance?
Phase-Change Materials	Inexpensive Small No maintenance	Still testing No hot climates?	Engine-alternators	Common Cost reasonable	Fuel and exhaust Noise
Thermo-Electrics	< 85°	AC = $50-100/yr Extra cabinet	Flywheels	Can be buried 7 yr maint.	Cost 6+ times
DC output Fuel Cells		Volatile fuel Heat Water Noise?	AC output Fuel Cells		Volatile fuel Heat Water Noise?
Li-polymer batteries	40% smaller 60% lighter No gas No maintenance	Will cost 2-4 x? Few sources Charge control Extra heat ckts.	MicroTurbines		Fuel and exhaust Noise
			DC Generators	Cost reasonable	Fuel and exhaust Noise
Ni-Cads	Proven 10-15 yr life	Water 5 yrs Cost 2-4 times Gassing Recycling Few mfgs.	Li-ion batteries	40% smaller 60% lighter No gas No maintenance	Still developing Will cost 2-4 x? 40 A-hr largest? Few mfgs. Charge control

HOW TO DO AN NPV ANALYSIS

Several costs must be taken into account when performing an NPV analysis:

- Initial Cost
- Maintenance Costs
- Replacement Costs

One thing not considered in an NPV analysis is the equivalency of the solutions in terms of reliability and other factors. To do a true "apples to apples" NPV, the costs of one of the solutions may need to be increased to get this equivalency.

There are two types of costs: those that occur one time, or at periods greater than 1 year; and those that occur every year. The formulas for these two types of costs are given below:

$$P_{NPV} = F_{\$} \times (1 + i_{\text{int}})^{-yr}$$

$$P_{NPV} = A_{\$} \times \frac{(1 + i_{\text{int}})^{yrs} - 1}{i_{\text{int}} \times (1 + i_{\text{int}})^{yrs}}$$

P = the present cost equivalency, F = the future cost we are trying to convert to present dollars, and "i" = "the time value of money" (the interest rate one could get if the money were invested rather than using it now). A = an annualized cost that occurs every year.

The formula for regularly recurring annualized costs only works if the costs stay constant. If the user decides to factor in inflation, then the first formula must be used every time. The formula to determine the inflated value in the future is as follows:

$$F_{\$} = P_{\$} \times (1 + i_{\text{inf}})^{yr}$$

In the case of this formula, the "i" is the rate of inflation.

The spreadsheet Tables 3 and 4 for the sample NPV in the next section give a good idea of how to go about setting up an NPV analysis.

The Finance people in your company must determine what is an acceptable payback interval.

SAMPLE NPV FOR FLYWHEELS

To have any hope of competing at present prices against the lifetime cost of VRLAs, flywheels must replace not only the batteries, but the rectifiers as well. The assumptions used in this sample NPV (used to produce the graph shown in Figure 1) are only valid for a certain climate, for a regulated telephone company. The assumptions are given in Table 3, and the spreadsheet calculation results are given in Table 4.

Table 3
Assumptions for Sample FlyWheel NPV

Assumptions			
installed VRLA battery	$0.29	/W-hr.	based on $2500 for 180 A-hrs of -48 V strings
installed DC plant	$8.27	/W	based on $7000 for 20 A load -48 V plant
flywheel replaces plant too	yes		
nominal voltage	-48	V	
current drain	20	A @ -48 V	
battery reserve	8	hrs.	
inflation rate	2.0%		
cost of money	11.8%		
labor cost	$45.70	/hr.	
yearly batt. maintenance	4	hrs.	
yearly batt. monitoring	0.5	hrs.	
yearly DC plant maint.	3	hrs.	
batt. replacement interval	3	yrs.	in desert for new Dynasty Robusts
study life	20	yrs.	depreciation life
installed flywheel	$2.34	/W-hr.	battery & DC Plant replacement
flywheel maint. interval	7	yrs.	
flywheel maint. cost	$182		
flywheel and DC plant life	21	yrs.	

Table 4
Calculation Results for Sample FlyWheel NPV

Year	Batt & DC Plant $	Batt Plant M$	Batt & Plant NPV	Cumulative Batt Plt NPV	Flywheel $	Fly Maint	Fly NPV	Cumulative Fly NPV	Fly Break-Even
0	$10,163	$0	$10,163	$10,163	$17,971		$17,971	$17,971	($7,808)
1		$350	$313	$10,476			$0	$17,971	($7,495)
2		$357	$285	$10,761			$0	$17,971	($7,210)
3	$2,358	$364	$1,948	$12,709			$0	$17,971	($5,262)
4		$371	$237	$12,947			$0	$17,971	($5,025)
5		$378	$217	$13,163			$0	$17,971	($4,808)
6	$2,503	$386	$1,479	$14,642			$0	$17,971	($3,329)
7		$394	$180	$14,823		$209	$96	$18,067	($3,244)
8		$402	$165	$14,987			$0	$18,067	($3,080)
9	$2,656	$410	$1,123	$16,111			$0	$18,067	($1,956)
10		$418	$137	$16,248			$0	$18,067	($1,819)
11		$256	$75	$16,323			$0	$18,067	($1,744)
12	$2,818	$261	$807	$17,130			$0	$18,067	($937)
13		$266	$62	$17,192			$0	$18,067	($875)
14		$271	$57	$17,249		$240	$50	$18,117	($868)
15	$2,991	$277	$613	$17,863			$0	$18,117	($255)
16		$282	$47	$17,910			$0	$18,117	($207)
17		$288	$43	$17,953			$0	$18,117	($164)
18	$3,174	$294	$466	$18,419			$0	$18,117	$301
19		$300	$36	$18,455			$0	$18,117	$337
20		$306	$33	$18,488			$0	$18,117	$370

ESTIMATED PAYBACKS OF ALTERNATIVES

The following estimated payback intervals in Table 5 are for a regulated telephone company in an Arizona desert climate. The results will vary by climate, industry, and by altering many other assumptions. These tables are just meant to give an idea of comparison of payback intervals.

Table 5
Estimated Payback Intervals for VRLA Battery Cooling Alternatives

Alternative	Payback?	Notes
CoolCell™	4-8 yrs.	Dependent on battery and cabinet size
Thermo-Electrics	4-8 yrs.	Dependent on battery and cabinet size
Burial	20+ yrs.	
Air-Conditioning	10 yrs.+	
Phase-Change Materials	5-10 yrs.?	Still testing for how much it lengthens battery life in different climates
"Cool" Plate	< 5 yrs.?	Unproven
Ni-Cads	6-10 yrs.	Dependent on physical size of battery
Li-ion batteries	8-15 yrs.?	In infancy
Li-polymer batteries	8-15 yrs.?	In infancy
Flywheels	12-20 yrs.	Even longer if only batteries replaced
AC output Fuel Cells	15-20 yrs.?	Depends on Regulatory for battery reduction
DC output Fuel Cells	12-16 yrs.?	Depends on Regulatory for battery reduction
Engine-alternators	10 yrs.?	Depends on Regulatory for battery reduction
DC Generators	10 yrs.+	Depends on Regulatory for battery reduction
MicroTurbines	15-20 yrs.?	Depends on Regulatory for battery reduction

ALTERNATIVES PRESENTLY IN USE OR TRIAL

Table 6 shows present deployments, research, and trials for use in outdoor equipment cabinets for the various alternatives. This list is not comprehensive; it simply reflects the present knowledge of the author.

Table 6
Deployments and Trials of the Alternatives to/for VRLA Batteries in Hot Outdoor Environments

Alternative	Where it's at
CoolCell™	Used by Qwest Previous deployments by Sprint Trials: BellSouth, GTE, and SBC
Thermo-Electrics	Used now by Sprint Used some by Qwest Used in some CATV applications
Burial	No known widespread deployment
Air-Conditioning	Used mainly on larger huts/CEVs Some use in CATV cabinets
Phase-Change Materials	Soon to be trialed by Qwest
"Cool" Plate	Soon to be trialed by Qwest
Ni-Cads	Used by SBC
Li-ion batteries	Misc. trials and small deployments
Li-polymer batteries	Trials by BellSouth and Telcordia
Flywheels	Trials by Telcordia & a few others
AC output Fuel Cells	Under study and discussion
DC output Fuel Cells	Under study and discussion
Engine-alternators	Widespread CATV cabinet use Some telephony cabinet use
DC Generators	CATV cabinet use Some telephony cabinet use
MicroTurbines	Cabinet deployment is minimal

THE ROLE THAT VEHICLES PLAY IN THE FUTURE COST OF THESE ALTERNATIVES

Many of the alternatives listed (e.g., Li-ion batteries, fuel cells, microturbines, PCMs, thermo-electric, flywheels, etc.) are not new technologies. However, their application as telecommunications backup or source is new. This often involves different manufacturing equipment and sizes. Also, some of the technologies (e.g., Li-polymer batteries, the "cool plate", etc.) are new. In either case, the scale of production is not there to bring the prices down. This brings us to the chicken and egg theory. The price won't come down until they are bought (and thus, manufactured) in mass quantities. They won't be bought or manufactured in mass quantities until the price comes down.

Why do lead-acid batteries have such a low initial cost? Because they are produced in mass quantities. The reason for this is the automotive industry, which uses about 90% of the lead-acid batteries in the world. Even though VRLA backup batteries are different than automotive lead-acid batteries, some of the manufacturing processes and tools are the same. The recycling process is the same also.

This brings us to how electric vehicles can play a role in driving down the cost of some of these alternative technologies. This would quicken the payback interval, and make some of the alternatives more palatable to Finance departments.

The electric and hybrid-electric vehicle industries are presently funding and studying several technologies, including:

- Li-ion batteries
- Li-polymer batteries
- Advanced VRLA batteries
- Ni-MH batteries
- Ni-Cad batteries
- Flywheels (for regenerative braking)
- Fuel cells

Any technology widely adopted for this industry has to be well-constructed to withstand the rigors of start-stop motion, crashes, hot vehicle compartments, etc. The technology can be easily adapted for stationary use.

The key is whether the EV industry ever gains wide acceptance, either through Regulatory mandates, or by customer acceptance. This would drive the volume production of some of the alternative technologies.

In addition, the regular internal combustion automobile industry is looking to adapt to a 42 V DC system for running all the power-hungry computers on board a modern car. They are also looking at potentially having 2 separate battery systems: one for starting (high-rate discharge), and another for running all the electronics (long-duration discharge). This work, and the funding the automobile industry sinks into it, could also result in battery advances.

CONCLUSION

As noted, there are plenty of alternatives available to get better life out of the backup power system in hot outdoor environments. However, reliability and cost of the alternatives are big factors that must be compared.

A proper NPV analysis can take care of the cost portion of this. The NPV analysis will be unique to the user's Finance department figures, their climate, the application, Regulations, etc.

Electric vehicle deployment could drive enough production to allow some of the alternatives to lower their initial cost. This will shorten their payback interval.

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