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A Simplified, Pragmatic Method for Determining Cost Effectiveness of UPS, Battery and Flywheel Alternatives

Abstract
Specifying UPS systems today can be a true nightmare. "Line Interactive", "Double Conversion", "Continuous Power", etc., etc – the marketing never seems to stop. The choice between DC alternatives such as wet batteries, sealed batteries, or flywheels is confusing enough. The author presents a performance-based approach for filtering out the hype and determining the right system for your particular application. The method is simpler than most, yet marries relevant practical performance criteria to real world cost concerns. After establishing your mandatory specification minimums for qualification, and both installation and basic operating cost issues, a weighting system processes the vendor-to-vendor differences in dynamic performance and site compatibility issues. Owners and their engineers change weighting as suits their particular application. For example, electrical efficiency weighs heavily at 23 cents per kWhr, but very lightly at 3 cents per kWhr. Upon completion of the comparison matrix, weighing factors are applied to bid prices and the decision is made.

The primary objective of this paper is to provide a tool to the average critical power buyer for comparing the cost-effectiveness of dissimilar UPS technologies for specific applications. This is impractical if not impossible with conventional construction specifications. A secondary objective is to remove some confusion and perhaps a few myths normally associated with some construction specs.

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Uninterruptible Power Supply (UPS) systems have become a mainstay in literally all walks of commercial, industrial and government business today. UPS systems in this millennium not only back up large data centers, communication hubs and key defense sites, but also hospital operating rooms, benign but expensive manufacturing processes, and, increasingly, even basic offices. UPS system technologies can vary widely, with much complexity and equipment possibilities to consider. Choice of a UPS for a desktop PC generally may not warrant much analysis, unless there are dozens or perhaps hundreds involved in a single contract purchase. Conversely, choice of a very large UPS system in the megawatt range will invariably mandate detailed comparative analysis, usually requiring efforts of experienced consulting engineers in addition to in-house personnel. But what about that very large proportion of power protection applications in between? We will briefly examine some common priorities of the most power-critical users, those in the range of several KVA (KiloVolt-Amperes) to perhaps several hundred KVA. We will then try to offer a relatively quick & simple means of comparing major costs & benefits of UPS systems including energy storage options. The methods presented are a user guide only, and not meant to be all-inclusive or to in any way meant to replace a comprehensive engineering analysis.

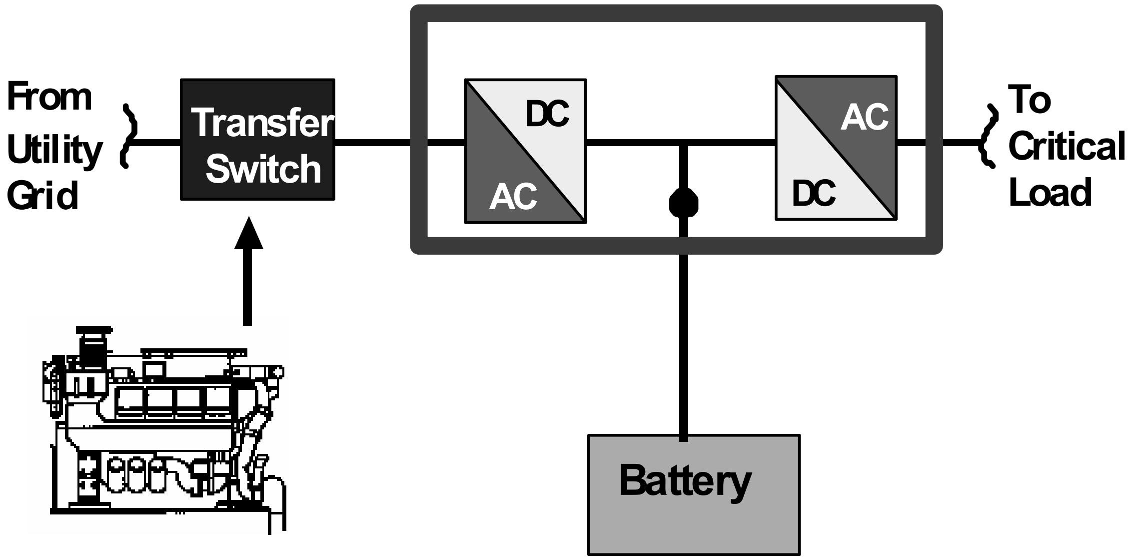

Fig. 1 Typical Critical Power system depicting UPS, battery & Diesel Generator

Some Preliminaries
In qualifying UPS systems & vendors for evaluation, there are a few preliminary questions you should ask. Make certain the system is minimally listed to UL 1778, the prevailing UPS standard. You might also consider require ISO9001 certification. Other standards and industry guidelines (CSA 22.2, IEEE 597, ANSI C62.41, etc) can also be included. There are lots of new & emerging technologies in power quality protection worth consideration & possible inclusion. But you may want to insure that whatever company is ultimately chosen, they will be around to support your product years later. Therefore, a requirement for minimum years in same or similar industry is a start. But fiscal accountability & stability may be even more important. Have your accounting department do some checking before choices are made.
Size & weight are not an issue for most UPS installations but they are for some. Insure space & floor loading are available for any system chosen. You will have to determine UPS electrical size. You will have both a KVA and a KW requirement. Both need to be met. Include sufficient room to meet at least a 3 to 5 year growth plan. Similarly, you will have a minimum requirement for battery or energy storage. Conventionally, 5 minutes reserve is most popular for those

systems backed by gas or diesel electric generation, while 15 minutes or perhaps longer is typically called out for non-diesel backed applications. You will also have to determine system configuration and required availability. Single module, parallel redundant, isolated redundant, external sync with static transfer switching are all possible options. As systems grow larger, there are also issues dealing with interrupting current and breaker coordination which must be addressed. You may need a PQ consultant to help with some of these key questions if in-house personnel are not up to snuff.

The issues

UPS systems come in a wide range of generic types, rotary & static, off-line or line interactive, no-break, double conversion, expandable modular, the list can get as long as marketing folk's imaginations. So how do we cut through all the verbiage & hype to get to the bottom line? Well, suffice it to say it will not be easy. But you can get a grip on at least the majority of important cost & performance issues to examine. These will include installed costs of equipment, reliability, efficiency, dynamic performance, battery or energy storage considerations, and more. Let's get started.

UPS Reliability
This is unquestionably first & foremost! Mean Time Between Failure (MTBF) ratings are a useful tool in comparing UPS systems. But be on guard here. MTBF ratings can be derived from calculated values such as the US government's MIL STD 217, or they can be empirically derived from user database data. Further, even empirical data may not be relevant if the equipment is not similar in class. For instance, a vendor might quote 1,000,000 hours MTBF over a database that is primarily systems using completely different architecture than the type you have been quoted. Adding to the confusion, they may or may not include battery failures. Under any circumstances, it is difficult to confirm or refute manufacturers stated MTBF values no matter how presented. One proven approach is to ask for a complete list of installed customers with same or similar architecture in your geography, then select five of these at random to telephone interview. A second approach is to contact UPS service companies in your area who service multiple vendors gear, but insure they are not "exclusive" with any one vendor. Use this information to evaluate & confirm vendors MTBF claims.

Energy storage
By a wide measure, the most common failure item or subassembly in any UPS system is either the battery or flywheel energy storage system. Since battery systems dominate the industry by more than 25 to 1, let's look at these first. Batteries are available in a variety of types but the most pervasive in UPS application are sealed Valve Regulated Lead Acid (VRLA) and flooded or "wet" cells.

Flooded Batteries
Flooded batteries are exceptionally reliable and often considered for large, mission critical applications where cost is incidental to uptime. If maintained correctly, they will last 10 to 15 years with only occasional cell or jar replacements to deal with. Importantly, the vast majority of cell failures in flooded battery strings are short circuit failures. This means that when a single battery does fail, you do not lose the entire storage system, as might happen with “open circuit” failures in VRLA or flywheel systems with key component failures. So flooded batteries are the ultimate in reliability in DC energy storage for UPS systems. But they are also very expensive, out pricing VRLA battery systems almost 4 to 1 on an installed cost basis due to special battery room construction considerations as well as equipment cost.

Fig. 2a, b 20 yr Flooded batteries/racks 10 yr VRLA batteries in cabinets

VRLA Batteries
VRLA batteries are overwhelmingly popular in virtually all UPS applications. Though not the equal of their flooded cousins, VRLA systems are routinely more than half their cost and size. These cells do not need to be refilled with water as flooded cells do, but they also have potential for open circuit failure due to dry out. This problem can be greatly mitigated if not eliminated by using a multiple string design and staggering string replacements. This technique improves VRLA battery reliability an order of magnitude and is covered in a separate paper by the author.

Flywheels
Flywheels are mechanical rather than chemical energy storage systems. These devices have a difficult time competing with VRLA batteries on cost, or flooded batteries on reliability, for the great majority of UPS applications. However, they can offer significant advantages in niche applications with very large systems (MW+) that are extremely space critical or perhaps for some third world applications with multiple very short outages daily.

Input Considerations
Ideally, UPS inputs should reflect no harmonic distortion (THD) and unity power factor (PF) for optimal wiring, utility and diesel generator treatment. In our real world, UPS systems that have full voltage regulation as well as continuous frequency regulation can reflect input THD levels of over 30%, far more than 5%

EPRI & ANSI recommendations. Filters can be added to reduce THD and improve PF, but be aware of their impact on space, reliability and cost.

Batteries and rectifiers

The type of rectifier used in a UPS can greatly impact battery service life and, therefore, system reliability. Today's UPS inverters employ IGBT technology which switches thousands of times a cycle. This greatly improves their ability to handle computers, and other harmonic or cycling loads. But many UPS systems use inexpensive rectifiers which switch only 6 or 12 times per cycle. The result is a time gap that must be made up by the batteries in constant charge – discharge cycling, as well as unwanted notching of the input waveform.

A second consideration affecting battery cycling is input voltage tolerance. Generally speaking, the wider the better. The great majority of power disturbances which impact critical loads adversely are undervoltage or "sag" events (ref: EPRI DPQ survey). A UPS which can tolerate say 30% undervoltage without resorting to battery will sharply reduce average battery cycling compared to a system which might go to battery after 15% voltage decay.

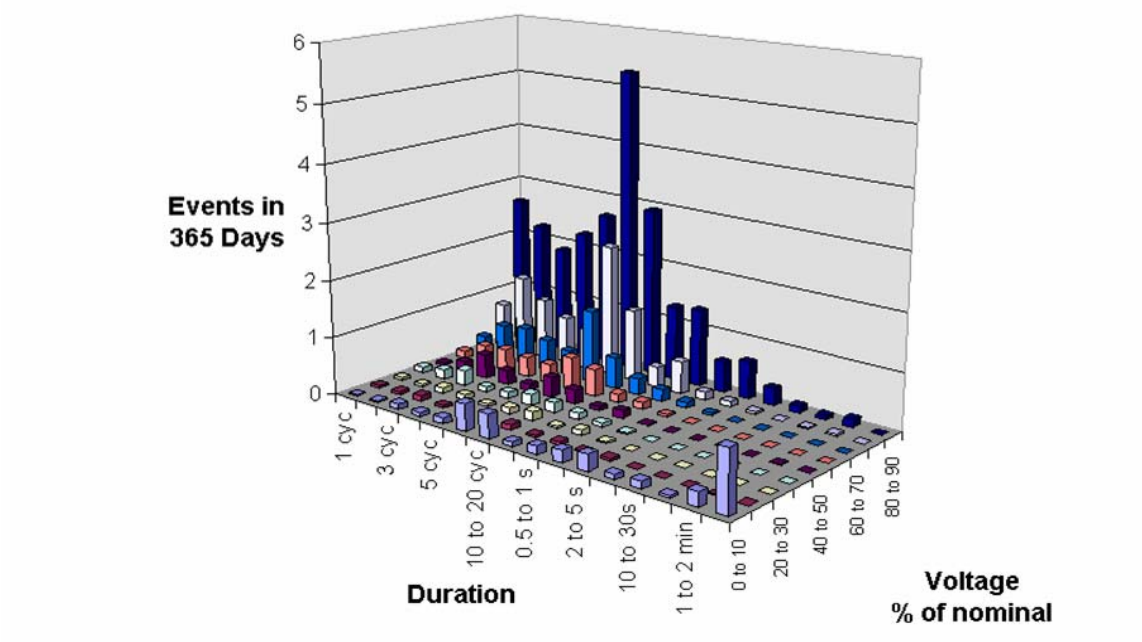

Fig. 3 EPRI DPQ Power Disturbance Chart

Lastly, the amount of AC ripple voltage & current produced by the charging system affects batteries. A system with less than 1% ripple is a good choice.

Efficiency, Frequency Regulation and Phase Control

All UPS systems exhibit losses or electrical inefficiencies as they operate. Some systems lose over 10% or more of the power supplied to their input terminals, others less than 5%, and everywhere in between. Of course, off line and line interactive UPS topologies exhibit excellent efficiency since they are not converting AC to DC then back to AC. But the trade off is the lack of continuous frequency regulation. This may not be critical to many single module UPS applications with high quality utility, but could become extremely critical in multi-module or diesel-backed applications with potential for out-of-phase voltages, or soft utilities with documented frequency aberrations.

Efficiencies are always second to reliability and power conditioning. Otherwise, you would just power critical loads off utility at 100% efficiency! But some scenarios rate more attention to utility costs than others. A system which is loaded up with transformers, harmonic filters and inefficient or outdated UPS technology will not only cost utility dollars, it will sharply degrade reliability as well. As a rule of thumb, figure at 50 KVA and $.05/Kwhr utility, a 95% efficient UPS will cost $1000/yr in losses while a 90% efficient UPS will cost $2,000/yr. For other UPS sizes or utility costs, adjust accordingly. Obviously, utility cost is 4 times the consideration at $.20/Kwhr than at $.05.

Dynamic Performance & Overload Capability

If you plan on running redundant or multi-module systems, or if you have cycling or motor loads, then step load and overload capability should be considered. For example, let's say you had a two or three module parallel UPS backed by paralleled diesel generators. In one failure scenario, you may have only a single module on line which could easily then be 50% overloaded. It could then be important to have sixty seconds of overload at that level to start and parallel diesels, then transfer critical loads. If the system were seeing cycling loads or isolated redundant instead of parallel redundant, 100% step load capability would be key since the entire output of the primary UPS would be dumped to the output of the standby system.

Warrantees & Service

After all the reliability claims are said and done, manufacturer's warranties speak loudly. As with automobiles, some UPS systems have become extremely reliable over recent years and those manufacturers reflect that in their standard warranties. Be sure to read warranty language on both UPS and battery. What you are looking for is best protection, usually written as "all parts & labor", for larger UPS (three phase systems), emergency response is also included in the standard warranty at no extra charge. Batteries will normally show both a full replacement as well as a "prorata" warranty period. Full replacement terms are always preferred since prorata warranties greatly reduce benefits over time. 1, 2 and 3 year full replacement or repair warranties are available on UPS and batteries as well. Make certain that factory trained & authorized service personnel are available in your local area providing no worse than 4 hour guaranteed response.

The Scaling

Now we get to the interesting part. Every UPS application is a bit different, with some factors absolutely critical for one, and incidental to the other. The user and/or their PQ consultant must decide how to weigh or scale these various factors for competing UPS vendors.

Start with the five year (or ten year) cost. That will be UPS, energy storage, all filters & support requirements, wiring & installation, and start-up. Add all required maintenance and 7 x 24 all parts & labor emergency service for a five year period and total. Utility costs can either be a separate worksheet item or you can roll these into the 5 year cost number. If one particular system ("A") costed out at perhaps $60,000.00 and another ("B") at $80,000.00, you would use the inverse of this proportion when scaling. On a 100 point overall scale for the majority of applications, the winning 5 year cost will routinely account for half to perhaps ¾ of the total. In the above example, system A was awarded 64 points and B got 50 points.

Now assign point values for those factors you have determined important for your particular application. Reliability is always the next consideration. In ultra critical sites, proven reliability may weigh even higher than five year cost! However, most midrange applications might assign point values in the 10 to 25 point range for UPS & battery/storage reliability. A system with 2,000,000 hours provable MTBF might be awarded 15 points while one with 1,000,000 hours receives 7.5 points. A system with 5% input THD and unity PF may receive 5 points while one with 10% THD receives 3. A system with 10% undervoltage might get 2 points while a system with 20% receives 4. Continue through establishing and scaling your point matrix. Below is a sample matrix factors for possible inclusion. At the end of the evaluation, the high point achiever is the recommended system.

SAMPLE SCALING MATRIX AND BID EVALUATION

Sample Feature or Factor	**Scaling / Weight**
Installed cost (UPS, frt, rig, wiring, filters,start-up)	40 - 75
Reliability (hrs MTBF) & warranties/service	10 - 50
Input voltage tolerance (without battery)	4 – 8 (UPS dependent)
Frequency regulation, continuous	2 – 10 (site dependent)
Wire & Diesel sizing (can build into 5 year cost)	3 – 6 (UPS dependent)
Overloading, 150%	3 - 6
Step Loading, 0 -100% (low V disturbance ideal)	2 – 8 (UPS & site dependent)
Size of system	2 + (site dependent)
Input THD (5% or less is ideal) & input PF	3 – 6 (UPS dependent)
Efficiency (can build into 5 year cost)	2 – 8 (utility dependent)
Unbalanced loading (% V reg with 100% imbalance)	0 – 6 (site dependent)

Genset compatibility	0 – 10 (site dependent)

Scaling Worksheet - One "Five 9's" Example*

Factor	Possible Points	Vendor A	Vendor B	Vendor C
Type		Line Interactive	Dble Conversion	Rotary
Installed Cost	50	46	48	32
Reliability	22	14	20	18
Warranty/Service	10	5	9	6
Input V	6	3	6	5
Input THD / PF	3	3	3	3
Efficiency/Utility	3	3	2	2
O.L. & Step Load	3	2	3	3
Total	**100**	**76**	**91**	**69**

*** No genset, $.06/Kwhr, 3000 sq. ft. data center, 7 x 24**

Conclusion: Vendor "B", although not the low bidder in this case, has highest score on scaling by a wide margin and gets the bid award as most cost-effective overall.

The Author

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