HITEC
Power
Protection

Executive Summary

Uninterruptible Power Supply (UPS) systems require an energy storage capability with sufficient capacity to bridge the time between the mains power failing and an emergency power source, such as diesel fuelled on-site generation, starting and taking over the load.

This storage has traditionally been electro-chemical batteries providing several minutes of support (so called, autonomy) or kinetic energy storage (flywheel) providing a few seconds, sufficient to cover the starting time of emergency diesel generators.

Although rotary technologies pre-date static, the Data Center Industry as a whole has been pro –battery UPS, with Rotary systems being employed in only 5% of cases. The pro-battery argument is based primarily on the longer autonomy time offered by the battery UPS compared to the Rotary system and the purpose of this paper is to review the value of the differing autonomy time between battery and flywheel systems and to assess the benefits of both.

- The main conclusion of the paper is that in spite of the industry's traditional preference for battery UPS, in many circumstances very little advantage can be gained from the extra time provided by the typical 10-20 minutes of battery autonomy (although decisions should always be made on a case by case basis)

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The Need For UPS

ICT hardware, such as that used for data computation, storage and communications, has an amount of in-built energy storage to enable it to 'ride-through' a total loss of supply voltage. This 'zero-volts' immunity capacity was defined within IEEE466 & 1100 and is widely known as the CBEMA , or, later, the ITIC, Power Quality Curve. The zero-volts 'ride-through', or 'hold-up', specification was revised over the years (significantly in 1997) but by 2012 is generally regarded to be at least 10 milliseconds (when the hardware is fully configured at maximum load) but nominally 20 milliseconds or even a little longer when the hardware is lightly loaded.

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To establish the possibility of providing continuous digital services from the data-facility we should first compare this CBEMA/ITIC requirement with the power quality supplied from the mains power supply system Clearly this depends upon the maturity of the grid but in the typical locations where data-centres are located (close to trading markets such as London, Frankfurt, Amsterdam, Paris & Madrid) the mains power deviates outside of the 20ms immunity limit every 150-250 hours and recovers in less than a few seconds. Unlike 'blackouts', a total loss of voltage lasting a few minutes or more which may occur less than once every 5 years in an urban location, these '>20ms failures' may not be noticed in normal facilities but they will probably cause a loss of digital services every week or so . This level of business continuity was tolerable in the early days of the mainframe (c1955 to the mid-60s) but is totally intolerable in today's 'always on, everywhere' digital society.

This is where UPS comes in, to solve this issue. The main function of a UPS is to improve the power quality delivered to the load to the point where excursions outside of the CBEMA/ITIC power quality curves are eliminated. To achieve this power quality improvement the equipment has to have access to an energy storage system that covers the time between mains 'failure' and 'restoration', or sufficient time to have emergency power generation start.

Not all data-facilities, especially in the <200kW range, have the benefit of emergency generators and so the UPS energy storage has to be in 30+ minute range but larger facilities are usually provisioned as standard with standby diesel generation.

Kinetic Energy in the Historical Context of UPS

No-break power rotary sets pre-date power electronics and were innovated in Holland for the Dutch Telecom PPT by a company called Heemaf (later Holec, now Hitec) in the mid-50s. The first mainframe computers were fed with aircraft-style 441Hz motor-generator sets with a very simple flywheel. The power rating of these early machines was typically 40-50kW with no more than 1 second of ride-through autonomy. Only later, when the power thyristor became available and suitable for power applications above 100kW, did 'static' UPS with batteries join 'rotary' UPS in the market. Rotary-UPS developed in technology, both with battery and kinetic energy storage, as well as in capacity whilst Static-UPS with battery storage expanded its market share dramatically. Rotary-UPS has always been manufactured in higher power modules that Static-UPS and that continues today, to the point that Rotary-UPS, and particularly integrated-diesel types (DRUPS), cannot be generally found in power applications below c500kW.

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Today, in 2013, the market share of Rotary-UPS with kinetic energy storage amounts to approximately 5% of the entire UPS market Static UPS account for a huge amount of the total market. It is interesting to note however, that the market share for Rotary UPS when only very large applications are taken into account (>2MW) is much larger at 35%.

Comparison of Battery and Kinetic Energy Storage Technology

Batteries are manufactured for three major applications; Traction (e.g. electric vehicles such as fork-lift trucks with daily deep discharge and recharge work cycles), Automotive (e.g. thin plate, short time, high discharge for starter duty) and Telecom (long discharge at low load) and each application dictates the composition and thickness of the plates. The dominant UPS battery technology in EMEA is from the Telecom range and of the valve regulated lead-acid (VRLA) type which has minimal gassing, no access to the electrolyte and whose maintenance is limited to routine cleaning, care of the terminal post connections and some form of temperature control for maximum life. They are most suitable for discharge rates of 4-8 hours but well suited to typical UPS applications of 10-30 minutes. The longer the discharge time the more energy can be extracted from the chemical reaction and so short autonomy times, e.g. 5 minutes, represent poorer value-for-money in terms of capital deployed.

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On the other hand flywheel technology is suited only to short discharge high power applications with an upper economic/practical limit of 10 seconds at full load.

(a) The Impact of Partial Load on Autonomy

Partial load is endemic in data-centre applications and the effect on the energy storage technology is dramatic, especially markedly in the case of batteries. System loads of 30-35% are very common and UPS module loads are, due to redundancy architecture, often no more than 20%.

Both flywheel and battery systems have an autonomy time that is not proportional to load. In the case of flywheel energy storage loaded to 20% this may result in autonomy times of up to 6 times that at full load, e.g. a 10s flywheel at 20% load will have c60s of usable autonomy. However the impact on a 15 minute VRLA battery of a 20% load will be to provide over 2 hours of autonomy.

(b) The Impact of Mains Failure

When the mains supply fails, or significantly deviates outside of the acceptable window of the UPS system, the UPS resorts to its energy storage system and, if available, the command is given to start the standby diesel generator(s). In the case of kinetic energy storage, the command is immediate (less than one second) but even with battery storage of several minutes there is no delay beyond 3-5 seconds in issuing the diesel start signal. The reason for this is that the other data-centre services, primarily the mechanical cooling system, need to be restarted as soon as is possible using the emergency power source. If the cooling system is not restarted then the temperature in the data-room will rise quickly and a risk of server shut-down from over-temperature (rather than power failure) will increase after a few moments. The actual time available depends upon the load density but with the average cabinet load of 5kW and cold-aisle containment the time available before cooling must recommence is in the order of 60-90 seconds.

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So, when the grid supply fails on a kinetic energy UPS, such as DRUPS (Diesel Rotary UPS), the integral diesel engine is started immediately and is carrying the load within 3-5 seconds, regardless of the actual load. During that period the kinetic energy store may have discharged typically 30-40% of its capacity.

Alternatively, with battery systems, the standby generator system is started with only a 2-3 second control system delay and is carrying the load within 10-15 seconds . During that time, and before the UPS is fed with power from the generator system, the typical 15 minute battery will have discharged only 2% of its capacity. The only advantage a battery system has is for short mains failures lasting less than 2 seconds where the diesel start command can be inhibited by the returning mains power. However these short discharges of energy from the battery have a detrimental effect on the life of the battery.

(c) Failure-to-start Risk Mitigation

Should a diesel engine fail-to-start (in either a kinetic or battery UPS system) there is, in reality, never enough time for the system (or the site personnel) to attempt a restart cycle, regardless of the available autonomy, since the need for cooling return overrides all such considerations. Redundancy in modules, both in kinetic and battery systems, ensures that a single failure-to-start event has no impact upon the load continuity.

Emergency diesel generation sets, properly maintained but purchased from the standard standby market, are generally regarded has having a 1:100 chance of failure-to-start events. On the other hand DRUPS, with its integrated diesel engine and precision control, is maintained to UPS standards and kept, by necessity, in peak starting readiness, is usually assumed to increase that starting reliability by a considerable factor to 1:8500. In both cases module redundancy reduces the impact of a single failure-to-start event affecting the load but the single system responsibility and maintenance contract of DRUPS is a key operational feature.

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Due to the ‘immediate’ starting control cycle of kinetic energy systems, the diesel engine does start more frequently than a standby/battery solution, and, depending upon the grid power quality, this can be frequent: In stable and ma ture grids (such as the UK, Europe and US) in the order of 10x per year to the extreme of 50x in areas of weaker supply. In very weak grid areas, e.g. certain Caribbean Islands, the grid supply can deviate sufficiently to cause kinetic energy based systems to call for a diesel start on a daily basis. The impact on DRUPS of a weak grid supply is an increased maintenance cost arising from the more frequent starting duty but this has to balanced by the fact that battery degradation in such environments can be a larger issue.

Other Factors in the Choice of UPS Energy Storage Technology

There are other factors that arise in the choice between kinetic energy storage (most frequently integrated within Diesel Rotary UPS) and battery energy storage (as exhibited in static UPS). These factors (and some comparisons) include:

System Responsibility

> DRUPS is an integrated system of short term storage and long term emergency power generation. Static-UPS with battery short-term storage requires separate emergency power generation that splits the system responsibility into two separate control systems. This integration is often regarded as a strength of DRUPS.

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> A single maintenance agreement is a strong feature of DRUPS but may result in higher cost than a Static-UPS/Battery/Genset solution due to lack of competition

Energy Efficiency

> DRUPS systems have historically been higher in efficiency (c96.5%) than Static-UPS, although Static-UPS, (particularly at partial load) has recently matched, and in some cases with modular topology, overtaken, DRUPS. This is however achieved by eco-mode operation which does not fully provide power conditioning.

> Partial load efficiency must be carefully considered and Static-UPS of a modular design can

provide an advantage where the load profile builds slowly over time albeit at an increasing component count and complexity. The key operating point for UPS efficiency is at 30-40% system load

> Rotary UPS equipment's provide a good low load energy efficiency (in excess of 90%) down to below 25% load.

> DRUPS installations do not require air-conditioning for battery protection which represents a 1% efficiency advantage over Static-UPS (c3kW per MW of IT load)

Space

> DRUPS saves 20-25% footprint over a 5-10 minute battery supported Static-UPS

> However, batteries can be more flexible in their use of footprint

> DRUPS is particularly suited to containerisation

TCO & Long Term Maintenance

> Most data centres are long term facilities. Diesel rotary UPS systems have a 25 year life whereas power electronic components (rectifiers and inverters) need to be replaced after 10 to 15 years.

> In areas where power costs are particularly high, 10-year Total Cost of Ownership (TCO) is dominated by the energy efficiency at the applied load

> Comparing maintenance requirements has to take into account the following major items for both cost and disruption:

> > For Static-UPS; fans (4 years), power capacitors (6 years) and batteries (between 4 years for the lowest cost to 12 years for the highest specification VRLA, or 15-18 years for flooded cells or NiCad)

> > For DRUPS: flywheel bearing replacement (8 years), Clutch and Engine refurbishment (mainly starting frequency dependent)

> > A client is best advised to ask for a 10-year index linked 'comprehensive' service agreement at the time of initial tender whichever type of technology they consider

Conclusions

Are batteries an under-utilised asset?

As with any technology choice a decision needs to be made based on an individual case scenario however there is strong evidence that in many cases batteries can be an underutilised asset, particularly in the case of UPS applications with standby emergency power generation. It is clear that, unless the cooling system is also fed by UPS (a potentially energy wasteful scenario), there is no possibility of utilising the additional stored energy that batteries provide. Design autonomy times of 10-20 minutes can be an under-utilisation of space, CapEx (for initial cost and cost of replacement) and OpEx (for maintenance) and typical UPS batteries in mature grid scenarios will usually only discharge for 10-20 seconds before recharging commences on generator power. Even 5 minute autonomy batteries, on the lower limit of practical design, fall into the same argument as they are hardly any smaller or less costly than 10 minute solutions.

There is strong evidence that in many cases batteries can be an underutilised asset, particularly in the case of UPS applications with standby emergency power generation.

Design battery autonomy times should not exceed 10 minutes unless specific application requirements exist and yet still offer support far in excess of flywheels but too little advantage.

The upside of battery storage is simple technology with low-tech service requirements that can be carried out by a wide choice of service organisations, or clients own personnel, other than the UPS vendor

What are the applications where DRUPS are best suited?

As a trend (which has been experienced to date) it is likely that DRUPS will continue to find that the application features that best suit the technology includes:

> Large systems, generally above 2MW of IT load

> Whole facility support, of the IT and cooling system loads, is achievable due to the better load handling capabilities of rotary UPS.

> Medium Voltage systems that feed an entire facility, both ‘critical’ bus and ‘short-break’ bus, enabling single UPS systems of over 30MW

> This solution is possible with Static-UPS but it is rarely seen in deployed systems to date and requires a separate MV generation system.

About Hitec

Hitec Power Protection is global technology leader offering dynamic rotary UPS systems - uninterruptible, continuous and conditioned power to mission critical applications. Core to this is the kinetic energy storage technology which Hitec pioneered more than 50 years ago. Hitec designs, manufactures installs and supports turnkey power solutions worldwide. Its headquarters are located in The Netherlands and has offices in the United States, United Kingdom, Spain, China, Singapore, Taiwan, Malaysia and Australia. Hitec delivers :

> Tailor made, cost-efficient power solutions

> A strong engineering team to supply turnkey projects

> Dedicated service and support

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