Cooling options for high-power UPS systems

Abstract

For many years it has been accepted practice to mechanically cool UPS plant rooms using close control (precision) air-conditioning systems to maintain the ambient temperature to within ±2°K of a set-point of around 22°C.

This practice has been combined with (or encouraged by) the need to control the ambient temperature of stationary lead-acid batteries to the same specification so as to achieve the longest possible service-life for the cells. It has been generally accepted that Arrhenius's Theorem[1] holds good for the relationship between design-life and service-life of a battery; a halving of the design-life for every 10°K above the base 20°C.

However the rising cost of energy has increasingly brought under the spotlight all parasitic energy consumers in the critical power-train. In addition some manufacturers of UPS and alternative energy storage systems to the battery have claimed that mechanical cooling is not required.

This paper investigates the topic and draws the conclusion that precision air-conditioning may not be required for all applications but some form of conditioned cooling is always to be recommended.

The scale of the cooling load

The problem should be split into two distinct parts:

- The UPS losses are rejected into the room and need mechanical removal. Modern UPS designs have 'nominal' operating losses of 2-6% depending upon size and operating mode. However any mechanical cooling system has to cope with 'emergency' conditions. This includes such operating conditions as minimum input voltage, non-linear load, short-term overload &/or battery re-charging. Under these conditions the losses can be closer to 7.5% for the largest double-conversion systems, equivalent to 75 kW per MW_{load}. It is worth noting that although the system will rarely be operating at full load (and the partial load efficiency is generally lower) the cooling system will never have to remove more absolute kW of heat.
- The battery losses on the other hand are minimal in normal duty - as low as 100W per 100kW of battery rating when floating. Even when discharging (when heat is generated by the current flowing through the resistive circuits) the thermal mass of the battery is so high as to slow the temperature rise. Allowing 2 kW per MW_{load} is sufficient - representing a tiny proportion (less than 3%) of the UPS losses.

Mechanical cooling options

With increasing levels of technical complexity and performance we can list the options available to the application engineer:

Fresh-air

The simplest system, and certainly the most reliable because of it, is electrically driven fans without filtration or humidity control. All critical power systems should have this as a back-up to a more sophisticated system and so access to an external wall without too long a run of ductwork is desirable. With a reasonable air speed the effectiveness (efficiency) of fan ventilation can be taken as 50VA of fan power per kW of heat to be removed but, clearly, there is no temperature, humidity or contaminant control from that of the external ambient air.

AHU (air-handling unit) system

With a larger cross-sectional area of ducting a very effective[2] contaminant filter can be incorporated into the ventilation system, along with broad-range humidifier and de-humidifier coils. The fan power has to be increased to around 100VA per kW (of heat removed) to overcome the higher static pressure. The delivered air is then only subject to the ambient temperature. The heated air is exhausted to atmosphere via exit ducts by the positive fan pressure.

Note that with both the fresh-air and AHU options there is little problem with temperatures below 0°C as variable dampers can modulate the cooling flow or frost heaters can be integrated.

Comfort-cooling (direct expansion) air-conditioning system

Comfort-cooling units only provide a wide-tolerance control of temperature and no humidity control at all. They are available in unit capacities of 3-20kW but, because they are very competitively cost-engineered, they are not generally designed for continuous operation in a high-reliability application. They are suitable (with run-standby arrangements) for battery-room cooling duty where a few days of lack of service will not create mission-critical issues. In terms of cooling efficiency these units consume the equivalent of 40- 50% of the heat that they transfer to the outside.

Close-control air-conditioning

CRAC units (Computer Room Air Conditioning) offer continuous close-control of both temperature (22°C±2°K) and humidity (50%RH±10%) with very high reliability. They are available in both direct-expansion[3] (DX) and chilled-water[4] (CW) in typical unit sizes of 20-100kW. The air in the plant-room is continuously cycled through the CRAC units. The overall efficiency (for a well designed but partially loaded redundant system) is in the order of 35-40% for DX and 25-30% for CW. It is to be noted that a poorly designed or severely under-loaded system with poor airflow management can be highly inefficient but it would be illogical to plan based on a failure in design or execution.

Dedicated UPS Water Cooling

A further option, and one where increased cooling system efficiency and lower losses can be achieved, is to directly cool the UPS modules from the buildings chilled water supply. This is accomplished by inserting an air-to-water heat exchange coil directly in the path of the UPS discharge and feeding the cooled air directly into the UPS inlet in a closed circuit. This option saves energy (as it avoids all short-circuiting of room air) and space and is particularly attractive in large plant room layouts that are not dedicated to UPS.

Humidification

This absorbs 15VA per kW of heat removed but only as and when required. As long as the delivered air is non-condensing a lot of energy (and maintenance) can be saved by not tightly controlling the Relative Humidity (RH).

Comparative losses

UPS machines are constructed to standards which include an operational temperature range of 0-40°C and up to 95%RH non-condensing, so, whilst it is clear that the battery needs the close-control of ambient temperature to maximise its life it is equally clear that the UPS modules do not.

In addition to the lack of precision required the battery cooling load is in the order of 3% of the UPS cooling load so it is clear that the battery should, wherever physically possible, be situated in a dedicated conditioned room. This leaves the UPS cooling options to be considered alone:

Conclusions

Batteries need some form of air-conditioning but the load is minimal and can be provided by low capacity and low-cost comfort-cooling in run-standby configuration. The most important design goal is to house the batteries in their own dedicated plant room.

UPS modules do not require close-control air-conditioning from a temperature point of view - as long as the external ambient temperature is expected to be less than 40°C and non-condensing. This is best provided by a dedicated and redundant fan AHU with filtration, heaters and de-humidification. Wherever possible the UPS plant room should be positioned against an external wall to keep the air-ductwork as short as possible.

All electronic power cubicles - including double-conversion, line-interactive, static, rotary or diesel UPS - will be adequately protected by an AHU system and don't actually need the traditional protection of CRAC units. The extra energy saving of a fresh-air system is not large enough in relation to the increased risk from contamination or condensation. There is a distinct advantage of increased reliability of an AHU over close-control air-conditioning from the simplicity of the system.

It is to be noted that some systems claim not to require air-conditioning (including diesel-rotary UPS and flywheel energy storage systems) but would certainly benefit from the filtration of cooling air provided by an AHU.

Typical cooling losses per MW of UPS

Cooling system	Temp control	Humidity control	Closed circuit	Filtration	Annual cooling load: Cooling kWh	Annual cooling load: Hun/dehum kWh	Annual cooling load: Total kWh	Annual cost @ £0.08/kWh
Fresh-air	No	No	No	No	32,850	0	32,850	£2,628
AHU	No	Yes	No	Yes	65,700	9,855	75,555	£6,044
Comfort DX	Course	No	Yes	Yes	295,650	0	295,650	£23,652
Close-control DX	Fine	Yes	Yes	Yes	246,375	9,855	256,230	£20,498
Close-control CW	Fine	Yes	Yes	Yes	180,675	9,855	190,530	£15,242

Reference

(1) Arrhenius' equation, first published in 1899, is more a rule-of-thumb than a theorem but accepted by all of the battery-industry as valid and applicable to the internal corrosion rate of VRLA cells
(2) Even to the degree of filtration required by IBM mainframe hardware
(3) Each unit has its own compressor and cycles refrigerant gas to an external heat rejection coil
(4) Fed with chilled-water (typically at 6-10°C) from a central cooling plant with a return temperature of 6-8°K higher

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With over 36 years experience of writing technical articles for leading companies and institutions, Ian is a world renowned author and speaker and an expert in all aspects of critical power and building services.