Improving PUE with the Use of Battery-Free UPS

Compressed Air, Rotary, Diesel, UPS – Introducing Air-DRUPS™

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Abstract: **Engineers at Pnu Power have harnessed the energy stored in compressed air to provide backup power without the use of batteries or flywheels. Reduced maintenance costs, improved efficiency, elimination of hazardous lead acid batteries, and the need for outside installations were all driving factors for the development of the Pnu Power Air-DRUPS™ (Compressed Air, Diesel, Rotary, UPS) system. Designers of large data centres (1MW+) that want to have a battery-free backup power system have very limited choices and only a few systems meet the needs of a modern data centre in terms of efficiency (PUE) and modularity. The Air-DRUPS™ solution offers a high–efficiency alternative that can operate reliably in hostile environments.**

I. Introduction

Lead acid batteries are the most common form of energy storage for backup power in data centres and other large critical power users such as hospitals. Flooded (wet) cells can be used and they offer a long life but they are expensive in terms of purchase price and require extensive regular maintenance. VRLA (sealed) batteries offer a cheaper alternative but have a shorter life of five to seven years (in ideal conditions) and require regular checking to make sure that bad cells are exchanged. Customers that want an alternative form of energy storage that doesn't contain lead or acid have a limited choice of various rotary (flywheel) systems. These systems require a standby charge because they continuously rotate and are typically in the form of small high speed flywheels or large steel flywheels. The autonomy (backup time) of these systems is typically less than twenty seconds and as such they are used to ride-through to a generator. Rotary systems (flywheels) that are mechanically connected are often referred to as DRUPS (Diesel, Rotary, UPS) or, if they are electrically connected, E-DRUPS. In the same way that a flywheel will provide the energy to support the load until the generator starts the Air-DRUPS™ system uses the energy stored in compressed air to achieve the same function. The major difference being that the Air-DRUPS™ system is stationary in standby and as such has much lower losses than the equivalent DRUPS or E-DRUPS system with the additional benefit of lower maintenance.

II. Improved PUE

Designers of data centres and large buildings place high importance on the efficiency of the building services such as lighting, cooling and critical power. The "green-grid" derived LEED and Breeam for data centre certifications, place a high importance on the data center energy usage and the PUE (Power Usage Effectiveness).

$$PUE = \frac{Total\ Facility\ Power}{IT\ Equipment\ Power}$$

The Air-DRUPS™ solution combines dual conversion UPS technology from the most respected companies in the industry; this is packaged with energy storage in the form of compressed air provided by Pnu Power. The dual conversion UPS equipment operates in exactly the same way as it would with a battery attached; the Pnu Power DC100 and DC200 systems provide a DC source of energy by connecting to the original battery bus.

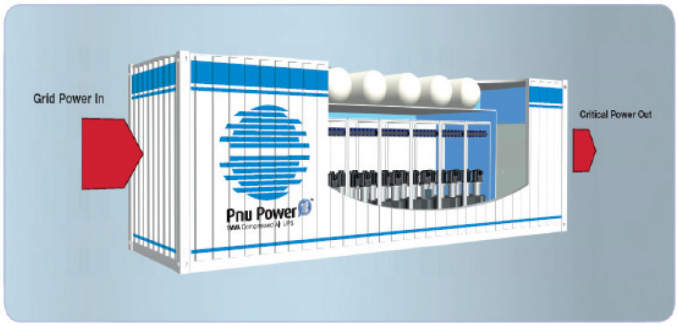

Figure 1 - Air- DRUPS™ 1MVA Solution

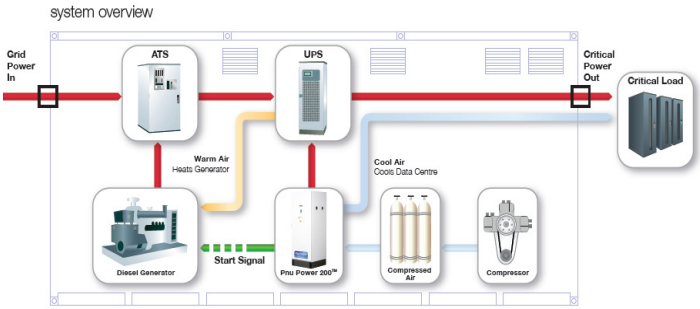

Figure 2 - Air-DRUPS™ – 1MVA Schematic

Traditional rotary DRUPS systems offer fifteen (15) seconds of backup time. To guarantee that the generator will start

within this period, the generator manufactures require that the engine is maintained at 42°C. The Air-DRUPS™ solution has a minimum of thirty (30) seconds of backup time which means that the generator does not need to start as quickly and can be heated to just 35°C. This saves energy that would normally be consumed by the block heaters. In addition, the hot air from the UPS systems can be ducted into the generator cabinet. This air is typically at 32°C+ and as such reduces the contribution of the block heaters to a minimal "top-up" to the required 35°C. Recycled energy is a factor that will shortly also contribute to PUE figures. The additional backup time allows the generator to be operated in a different way, the system provides a minimum of 30 seconds backup time, so at light loads this duration is much extended and at 50% load the system will provide over a minute of runtime. The Air-DRUPS™ system monitors the pressure of the compressed air and the volume of the cylinders is a known value so, the runtime can be accurately predicted. This allows the system to send a signal for the generator to start only when it is absolutely necessary and eliminates false starts due to small power blips of less than ten (10) seconds. With extensive compressed air available, an air-starter can be used to start the generator if the electrical start were to fail.

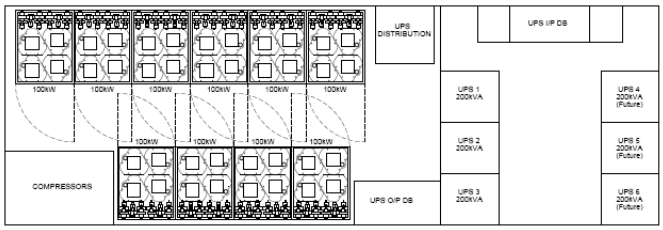

Figure 3 - Top View of Air-DRUPS™ (Scroll expander) and UPS Container

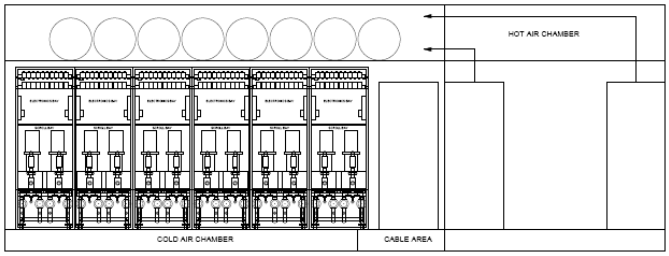

Figure 4 - Front View of Air-DRUPS™ (Scroll expander) and UPS Container

III. LEED AND BREEAM RATING SYSTEMS

Leed and Breeam are standards that are applied to the design and operation of buildings to ensure that they meet the latest targets for energy efficiency. Each standard has a points system for categories such as energy use, facility management and innovation. These points are weighted and added up to give an overall score for the facility. Energy use is the most heavily weighted category and as such, attracts the most scrutiny. These standards have been used for many years for office spaces and are now also being applied to data centers. The Leed platinum award and the Breeam outstanding certificate are reserved for the most energy efficient, well managed and innovative building. The Air-DRUPS™ system is one of the few battery-free UPS technologies that can achieve the required PUE figures for platinum rated data centres.

Figure 5 - Citi Data Centre - Frankfurt

The Citi data centre in Frankfurt (**Figure 5**) was one of the first data centers to achieve Leed Platinum status, data centre designers with aspirations of building the most efficient platinum rated facilities were frustrated to find that the traditional lead acid battery UPS was not contusive with the latest "Green Building " ethos. The Air-DRUPS is able to satisfy the needs for full dual conversion UPS technology without the massive standby losses associated with traditional DRUPS or flywheel technology. The Air-DRUPS™ offers a facility PUE of less than 1.3 even down to 25% load. This enables the data center operators to apply for Lead or Breeam certification long before the facility is fully populated. The design of the Air-DRUPS system is such that it is modular and offers inherent redundancy. Lightly loaded UPS systems can be instructed to go to sleep to save energy if necessary, this further increases the efficiency. A UPS system supporting a data centre would typically be running at less than 50% load, this is because of the additional redundancy, the fact that the system may be sized for future expansion and a tendency to oversize power equipment to offer the most conservative power protection solution. A DRUPS solution operating at 50% load is not very efficient because many of the bearing losses and power conversion losses are fixed regardless of the load, the Air-DRUPS™ solution is much more efficient in this operating range compared to the equivalent DRUPS solution because it does not have any moving parts in standby and uses the most advanced and efficient dual conversion UPS technology (**Figure 6** and **Figure 7**).

Air conditioning load is typically not connected to the UPS system and as such will trip out for a short period of up to a minute after the utility power fails as the generator starts and the air conditioning systems reset / restart. The Air- DRUPS™ system is producing cold air during this period as the compressed air is being exhausted from the scroll generators, this cold air can be used to cool the data centre until the air conditioning restarts by ducting the air into the room directly or via a heat exchanger. The cooling capacity of the 1MVA system is approximately 1MW of cooling for the period the

scrolls are running. The exhaust air temperature is typically below -50°C.

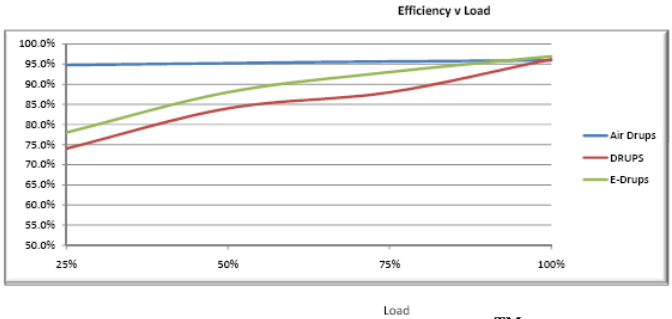

Figure 6 – Efficiency v Load AIR-DRUPS™, E-DRUPS and DRUPS

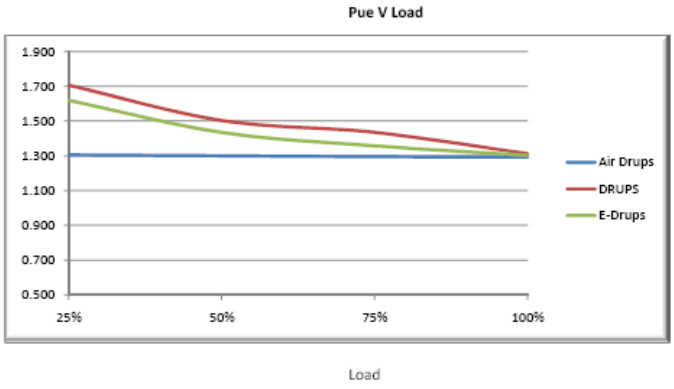

Figure 7 - PUE v Load AIR-DRUPS™, E-DRUPS and DRUPS

IV. Power Level and Control

Data centers are notoriously power hungry with blade server racks consuming over 15kW, the total load quickly exceeds 1MW. To satisfy this market demand, Pnu Power developed the DC100 and DC200 products using the same scroll generator technology perfected for the long duration (4 hour+) telecoms and utilities markets. The 100kW unit is made up of four individual 25kW building blocks which have their own electronic control and pneumatic systems for redundancy. The AC output of each of the four permanent magnet generators is rectified to DC and a current sensor detects the current level in order to accurately share the load. The system incorporates active load sharing and load following so that if a generator is disconnected the remaining generators will respond by supporting the additional load provided there is spare capacity.
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V. Reliability at The Heart of the System

The heart of the compressed air UPS system is a scroll expander. This is a complex piece of proprietary mechanical design that is based on a traditional scroll compressor; the difference being that it rotates when compressed air is applied (Scroll Expander, Refer to Figure 11). This rotation is converted into electrical power with the use of a generator.

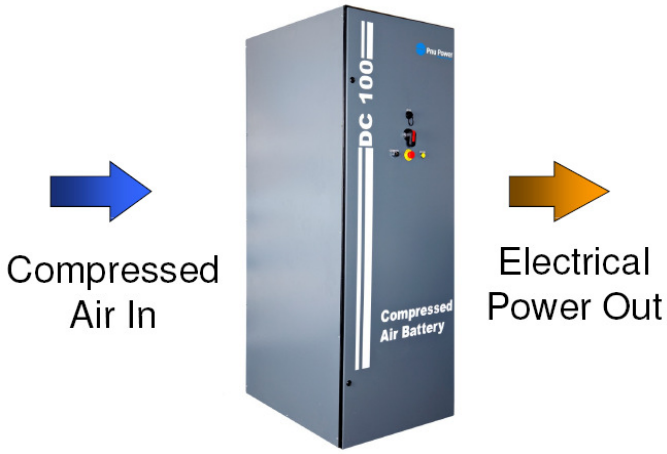

Figure 8 - DC100 (Compressed Air Battery)

Figure 9 - DC100 Compressed Air Battery - Internal View

Figure 10 - DC100 - Key to Components

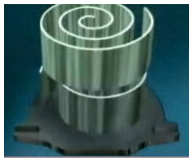

Figure 11 - Scroll Expander

A. *Response Time*

When the AC utility power fails, it is not acceptable to have any break in the supply of power to the critical equipment. Within less than a millisecond a signal is sent to a high speed air valve to open and pressurize the scroll expander, this starts rotating and generating DC voltage. The speed of the expander is regulated by adjusting the pressure which in turn regulates the DC bus to balance the generation against the load. The generator starts in less than 50 milliseconds and is fully up to speed in 200 milliseconds. However, even an interruption as short as this is enough to disrupt sensitive electronic equipment so capacitance is added to the DC bus to maintain the voltage until the scroll accelerates up to speed. On the DC100 and DC200 products, ultra-capacitors are used because of the large amount of energy they can store and the very low standby losses. The equipment works together to provide seamless backup power. The ultra-capacitor string designed for a 525 Vdc bus consumes less than 2.5 watts of power in standby. This is much less than a battery string or a string of electrolytic capacitors consumes.

B. *Control Electronics*

Off the shelf electronics are not available for this sort of application so a control board with a graphical user interface was developed in-house. This board uses a processor chip to respond to a loss of power and drive the necessary valves and regulators, it also monitors the air pressure and can be configured to predict the available backup time. Self diagnostics continuously check the system to make sure it is ready to respond.

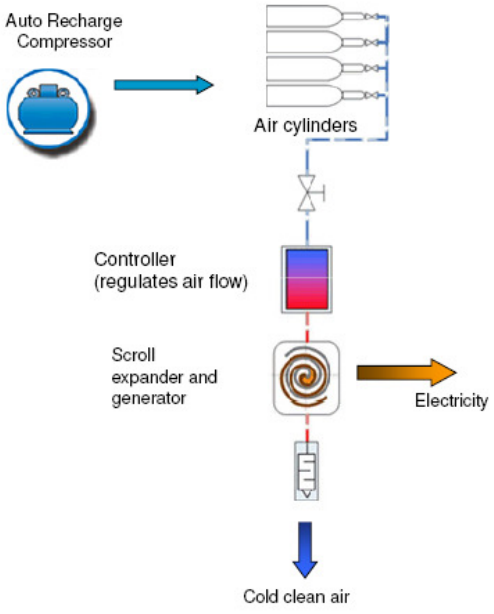

Figure 12 - Schematic of Compressed Air UPS

C. *Safety and Certification*

The compressed air battery technology was originally developed for backup power in high voltage substations. Prior to installation in these locations, the equipment requires evaluation and testing by third party organizations. The National Grid in the UK as with most worldwide utilities, require that equipment installed within their substations is registered with the Achilles certification and a stage-gate approach to product testing was carried out with factory testing and successful field trials completed before deployment.

Figure 13 - Accreditation testing

VI. TESTING AND EVALUATION

A total of over 30,000 discharges were completed prior to the systems being deployed to ensure they would support the load when required.

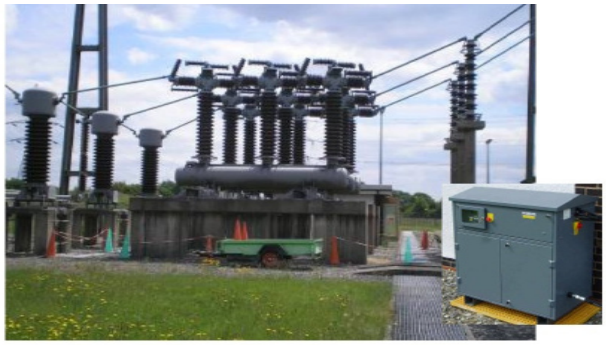

Figure 14 - National Grid UK- Capenhurst Site

A. *Hostile Environments*

Many of the PnuPower installations are installed outside in hostile environments, National Grid USA has to cope with more extreme environments than National Grid UK and as such, it was necessary to test the Compressed Air UPS System in these conditions. One of the benefits of the system is the fact that it can be installed outside which removes the need for expensive enclosures and or buildings.

Figure 15 - Environmental chamber

With this in mind each unit was subjected to +50°C (122°F) and -40°C (-40°F) temperature cycles over a period of weeks. The system has very low standby losses in the region of 30 Watts and as such has very little self heating. For units that operate below -20°C a small thermostatically controlled heater is added inside the cabinet to ensure reliable operation.

Figure 16 - National Grid USA- Barrington Site

B. Reliability and maintannce

The high reliability of the system is achieved by using the very best stainless steel pneumatic components for the valve train and through the design of the system that is stationary in standby; so wear only occurs when the system is in operation which is typically less than one (1) hour per year. Maintenance of the system is minimal with just an annual visual check of the valve train and test of the pressure relief valve. There is a check once every ten (10) years on the air cylinders (re-certification) and if a compressor is installed, this must be maintained in accordance with the manual which is typically a check of the belts every 200 hours and a pressure test to check the efficiency every 1000 hours which in a normal site would equate to every five to ten years depending upon the number of power disruptions.

VII. TOTAL COST OF OWNERSHIP

A battery-free soltion reduces the number of checks by half and provides a solution that doesn't need to be exchanged every five to seven years as with batteries. In many older sites the operation may be relying on flooded (wet) cells that require a lot more maintenance and special installations in terms of hydrogen monitoring, bonded flooring and eyewash stations. This can all be eliminated with a compressed air solution that can be installed outside, freeing up this space for other vital equipment. Large rotary systems that continuously rotate often need bearing changes that in many situations can not be completed on site due to the downtime required. High speed flywheels rely on fully or partially levated designs that have vacuum systems to maintain a high-vacuum to reduce windage losses caused by their high speed. These are often complex and expensive to maintain. The Air-DRUPS™ system is stationary in standby and as such does not need more than a few watts of power to maintain operation. A photovoltaic option is offered to reduce the power consumption to zero (carbon neutral) during the day.

VIII. Performance Summary

Criterion	DRUPS or E-DRUPS	Air-DRUPS™
Degradation	• Continuously rotating • Bearings wear out	• System is stationary during standby periods with no degradation • Degradation does take place during operation
Backup Time	• Typically, generator must start in 15 seconds	• Minimum of 30 seconds, more with extra cylinders
Maintenance requirements	• High • Regular checking of system • Complete overhaul every five to seven years • May require removal and reinstallation for refurbishment at the factory	• Low • Yearly inspection. • 10 yearly cylinder re-certification • Filters and belts on compressor every five years

IX. References

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[2] R. B. Schainker and M. Nakhamkin, "Compressed - Air Energy Storage (CAES): Overview, Performance and Cost Data for 25MW to 220MW Plants," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-104, pp. 790-795, 1985.

[3] P. C. Symons, "Opportunities for energy storage in stressed electricity supply systems," presented at Power Engineering Society Summer Meeting, 2001. IEEE, 2001.