One year operation of a 9 kW HVDC UPS 350 V at Gnesta Municipality data center

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Abstract - **The municipality of Gnesta, Sweden will in the future offer triple-play internet broadband services to its inhabitants. In the past the IT Service Department of Gnesta used small AC UPS of different ages to cope with the need for uninterruptible power backup at the data centre to match the reliability of telecommunications. Battery maintenance became a burden and they also found that this solution gave little or negligible back-up time.**

The IT-management of the Gnesta Municipality decided to try the HVDC UPS concept which seemed to promise superior transient protection, energy savings, reliability, power quality and economy.

This paper describes one year of trial and full operation of a 350 V DC uninterruptible power system, which may very well be the world's first in critical operation.

The paper also describes the HVDC UPS system, designed by Netpower Labs AB and used at the Gnesta municipality. As the first commercial system it meets the ETSI standard EN 300 132-3.

Since there currently are very few types of servers and data equipment specifically designed for direct operation from HVDC (350 V DC) Netpower has explored the possibility to use standard equipment and run them on HVDC as an intermediate step. Netpower has performed a study on various existing power supplies for data servers and other computer equipment to check their compatibility with the HVDC concept.

The energy savings potential of 30 % made possible by HVDC UPS (compared to present AC UPS) is discussed in the paper.

The conclusion is that a HVDC UPS 350 V gives superior transient protection, great energy savings and has potential for future enhanced data centre energy savings as well as it offers very high reliability and good economy.

I. INTRODUCTION

Gnesta is a growing municipality south of Stockholm. Like many other municipalities in Sweden and all over the world the Municipality of Gnesta establishes as optical fibre-LAN operator and ISP offering triple-play broadband services to its inhabitants. This implies a need for uninterruptible power backup at the data centre to match the reliability of telecommunications. The municipality's main data centre used to have 5 small (2 kW 5-10 min backup) standard AC UPS of different age. Always one of the UPS:s alarmed because the batteries needed to be changed and the maintenance became a burden. This solution gave negligible back-up time. Consequently a number of service interruptions occurred. The main data centre needed upgrading and headroom for expansion. The cooling system had no reserve power installed and had a very high energy consumption.

At this point the IT-management of the Gnesta Municipality decided to try the new HVDC UPS concept including one large reserve battery as being superior in

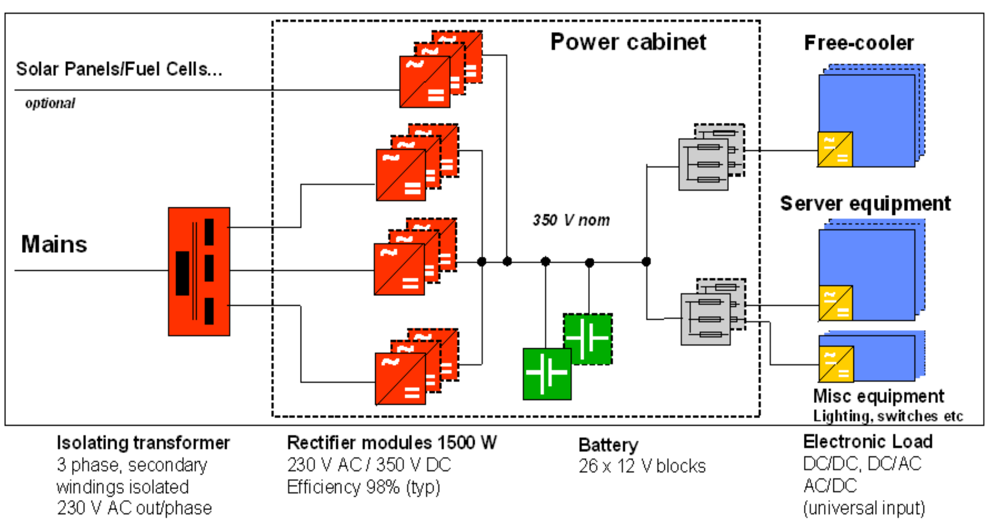

Fig. 1. Netpower HVDC UPS system as delivered to Gnesta

transient protection, energy savings, reliability, power quality and economy. A new low energy free cooling system was selected and supplied with reserve power from the HVDC UPS.

II. HVDC UNINTERRUPTIBE POWER SYSTEM

The HVDC UPS system, designed by Netpower Labs AB is the first commercial system which meets the ETSI standard EN 300 132-3. It operates at a nominal 350 V DC system level. In a three phase connection it comprises an isolating transformer and per each phase a number of non isolating rectifier modules (in parallel redundancy), batteries and distribution. The system gives very high efficiency, is highly reliable and gives superior transient protection and power quality. See figure 1.

The isolation transformer shall not necessarily be considered an extra conversion step. In many data center installations an isolation transformer is specified anyway for transient suppression, protective purposes or elimination of ground loops. The isolation transformer also makes it possible to feed the installations directly from an incoming high voltage power line.

The transformer can be located in any convenient location in the building.

Fig. 2. 1.5 kW Rectifier – One of the key components of the HVDC system

The rectifier's input current, taken from the mains, mirrors the input voltage sine wave and is also in phase with the voltage. This is why it feeds no distortion or harmonics back to the mains. The unit is non-isolating and can operate unlimited numbers in parallel. This feature makes the unit outstanding in efficiency and it enables very high system reliability.

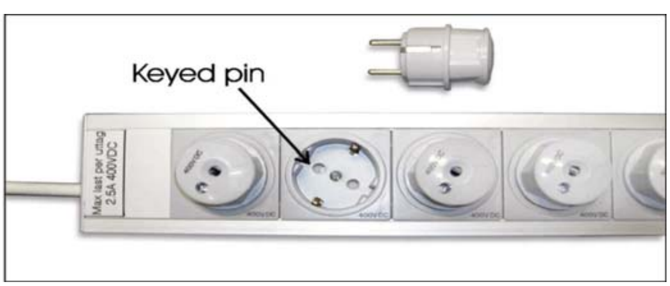

Fig. 3. Plug and outlet for 2.5 A, 400 V DC

Key data:
- Input: 230Vac +/-15%
- Output: 350V/1500W
- Efficiency: 98% (half load)
- Operation: -25°C -> +50°C
- Dimensions: 140x45x290mm
- Volume: 1,5 dm3
- Density: 1000 W/dm3
- Weight: 750 g

Features:
- Pure sinewave current input
- Overload protection
- Thermal protection with derating
- Redundant fan cooling
- Short circuit protection
- Power factor close to 1.0
- Extremely low output ripple
- Very high MTBF (few components)

Tab. 1. Rectifier highlights

The plugs and outlets to connect the equipment are standardized by the Swedish Electrical Commission. The plug and outlet set has been tested and approved for making and breaking of 2.5 A, 400 V DC.

The standard appliance cable set is replaced with a cable set including the 2.5 A 400 V DC male plug, a box including fuse and trigger circuit and a standard 10 A IEC appliance connector with an instruction flag. The box includes a special circuit for those server types which needs triggering pulses to start, explained later in this article (Table 2). It also comprises a special 400 V DC rated fine fuse needed to take over the normal 250 V AC fine fuse embedded in the powered equipment, mandatory for protection of an appliance. The standard type IEC connector is not rated for breaking DC but is permitted for DC use if it is fixed with a strap to the appliance and equipped with an instruction flag telling that it is allowed to disconnect with a tool only after the appliance is switched off.

Fig. 4. DC Cable Set for connection of appliancies

III. TEST PERIOD

The system was commissioned and installed during February and March 2006. The first test period was run with three standard PC:s as load for two months until end of May without any observed malfunction. During the spring Netpower tested Gnesta data centre´s different server power supplies in its laboratory. Spare units were bought for this purpose and server simulator circuits were developed and connected to the power supplies. In the laboratory all power supply types (originally rated 230 V AC) with the exception of one were successfully run on 350 V DC without any modifications.

A. First run

However, when first connecting the most common of servers at the data centre in Gnesta in May we failed!

One of the units that had started nicely in lab environment did not start in the field. After more trials in the laboratory we found out that the unit needed some type of triggering pulses on the input to securely start on DC. Also it was observed that it mostly started at elevated voltage. By request from our customer Netpower started to design a trigger circuit, which is now included in the cable set box. A second type of power supply unit started without trouble although it alarmed “power no good”, but it run with no problems at all. The “power no good” alarm was not used for any purpose in the equipment and it was decided to simply neglect it, in agreement with the customer.

B. Intermediate solution

As the summer period, the season for thunderstorms and power outages in Sweden, now came very close, Netpower decided to offer Gnesta Municipality to use a standard AC UPS as back-up until all servers could be safely put into service on the DC UPS. Also it was decided that the DC UPS should be equipped with an AC inverter connected to the HVDC UPS to feed the single server which was not accepting the 350 V DC. This would make the system more flexible and universal and at the same time providing the operational reliability of being supplied from the HVDC UPS system.

C. Second test phase

In June the second test phase started as three different types of the data centres servers were put into service with a trigger circuit prototype, and by “repeat-plugging” the power cords of the servers which did not start immediately.

Also a free cooler with power back-up was put into service. The free cooler works on 48 V DC and is powered by a standard 48 V rectifier of SMPS type fed from 350 V DC. During summer and autumn 2006 until January 2007 all equipment powered by 350 V DC worked properly showing no mis-functions.

The data centre managed to run during two 30 minute power outages and numerous thunderstorms without service interruption.

D. Third test phase – full HVDC operation

The third test period started in March 2007. Now all the equipment in the data center was switched over to the HVDC UPS. The temporary AC UPS reserve power equipment was removed.

All equipment, except two servers, worked fine on dc. Two 1 kVA inverter units were installed to supply power to these two servers. Since 350 V DC input inverters were not readily available on the market 220 V DC input units (input range 180 – 265 V) were selected. To reduce the 350 V system voltage level to acceptable 255 V, two Netpower’s rectifier units were modified and used as step down regulators in front of the inverters. In future installations only one small step- down regulator will be needed for that purpose.

Totally 20 standard servers and other equipment including the free cooler are in full and commercial operation on the 350 V HVDC UPS.

Fig. 5. A 9 kW Netpower HVDC UPS.
The distribution fuses (standard diazed type - certified for 400 V DC operation) are shown in the top row. Between these and the row of circuit breakers (feeding the rectifiers) the computerized supervision module is hidden behind the front plate. The 6 rectifiers and the battery fuse are seen below them. The battery is positioned at the bottom.

IV. **HVDC** UPS FEEDING STANDARD POWER UNITS

The demand for energy savings and CO_2 reduction will lead to market availability of replacement power supplies designed for 350 V DC for servers and other data equipment. As an intermediate step Netpower has performed a study on various existing power supplies for data servers and other computer equipment to check their compatibility with the HVDC concept.

The purpose of this investigation is to explore the possibility and evaluate pros and cons of feeding DC to existing power supplies designed for AC instead of waiting until all computer equipment is available in DC versions. As it will be seen the conclusion is that existing power supplies in many cases can be run off 350 V DC in a safe way, without violating standards and sound design criteria.

The most common loads for UPS are computer centers, servers and peripheral equipment. Other loads for UPS may be life sustaining equipment in hospitals, office computers, emergency lighting and process industry. The applications are numerous and all of them are vital, sensitive and crucial.

A. The switch mode power supply unit fed from ac

On a large scale we nowadays use electronic equipment and illumination with built-in switch mode power supplies, SMPS, composed of three fundamental parts, Fig. 6. (A similar configuration with the DC/DC converter replaced by a DC/AC low respective high frequency inverter is used in variable speed drives and eletronic ballasts for lighting.)

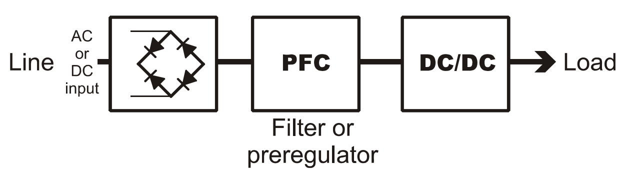

Fig. 6. Structure of the switch mode power supply unit

The basic design is a rectifying circuit including a filter or a preregulator, followed by a DC/DC converter. The rectifier converts the ac voltage to dc voltage, approximating the peak value of the ac voltage. The rectifier part of the power supply unit tends to feed distortion back into the ac system in the form of current harmonics, see Fig. 7.

This distortion may cause problems in the AC mains and for the AC UPS inverters. As a remedy, the AC/DC part of the power supply is provided with an active or passive power factor correction circuit, PFC. Active PFC, the more effective solution, means introduction of an extra conversion step in the power supply, while the passive PFC comprises filter chokes in various configurations. The PFC circuit adds complexity and despite added components they are seldom effective in performing their task in smaller units. Instead they increase the internal losses and decrease the units efficiency.

The overall fact is that many power supplies tend to heavily contaminate the AC mains with distortion and disturbances.

B. The switch mode power supply unit when fed from dc

From Fig. 6 it is obvious that it ought to be fully possible to feed most switch mode power supplies with dc. Principally they are universal input devices that can be connected to either 230 VAC or 350 V DC as you wish. (350 V DC is close to the peak value of the alternating voltage). This introduces an opportunity to reduce the unfavourable loading of the ac mains network and to eliminate the disturbances and problems in AC UPS systems. A DC/DC converter injects no harmful low frequency overtones back in the source, of course, see fig 7.

If exclusively direct current is to be distributed to the equipment, as from a DC UPS, the power supplies can be designed as DC/DC-converters only. The rectifying part - and the preregulating PFC is no longer needed. The power supply will be cheaper and have better efficiency. The efficiency of the power unit will be increased by 2-5%. This may sound negligible but considering the vast numbers used worldwide the macro prospects for energy saving is tremendous.

Thus the HVDC UPS would give the best results if it is used with loads including switch mode converters specially designed for the uninterrupted DC voltage. That would allow the designers to fine tune performance to highest possible efficiency and reliability and also save some money in components since equipment designed exclusively for DC input is less complex and has a lower component count than SMPS AC/DC units.

However, presently there are very few types of computer equipment designed for dc exclusively.

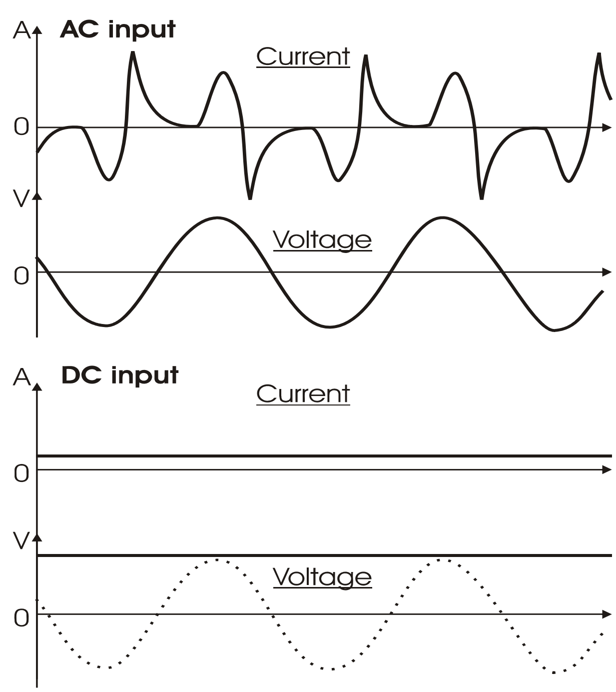

Fig 7. Input currents to SMPS with passive PFC, fed from ac and dc. (Same load, scale and power supply.)

V. Testing proves that many existing AC units can operate from DC

Netpower Labs AB has tested a large number of power units to find out which of them would accept a dc input, with only minor external modifications or no modifications at all.

The analysis of the test results shows that there are principally four different categories depending on design inclinations. The categories and their implications are explained in table 2.

As for fluorescent lighting - all tested types with HF ballasts work fine with dc input. This provides excellent options for emergency lighting. The same goes for many types of energy saving light bulbs including the new high-intensity LED spotlights. Old types of fluorescent lighting with inductor ballasts will of course not work – category 4!

This responds to the question from many owners of data centers, ***"I realize the advantages with DC UPS, but must I replace all my existing equipment?"***.

The answer is that many existing units indeed work fine on dc. However, there is always a need to do a survey, and sometimes testing, before dc is introduced as a power source for an existing plant. Some equipment needs special measures to be taken, but in most cases problems are easy to solve.

Fuses or circuit breakers certified for dc must always be used for the equipment, either by replacing existing fuses or by introducing an additional external fuse.

Another question often put forward is if running on dc hurts the existing equipment, originally designed for ac. Analysis and affirmative testing shows that running from dc rather tends to increase lifetime of the equipment due to lower continuous stress and less exposure to transients including dangerous dips and spikes on the input. A properly designed unit for 230 VAC normally also has the appropriate internal isolation and creepage distances for 350 VDC operation as well.

Fig. 8. "Server simulator" for testing of embedded power units

Category	**Design**	**Operation on DC**
1	AC units with input rectifiers (with or without active PFC circuits) and straight forward switch mode DC/DC design in the conversion circuits.	Category 1 units usually work excellently from 350 V DC, without any problems whatsoever.
2	Same as category 1, but where the designers for some reason have taken shortcuts in the design using capacitive couplings or mains frequency transformers to produce internal voltages (e.g. for starting the equipment or for signalling).	Very often category 2 units are dependent on the polarity of the applied dc voltage to operate. With the right polarity sometimes they have to be started by temporarily applying a series of pulses on the dc input voltage during start up. Once started these units operate fine off the uninterrupted dc voltage.
3	Same as category 1, but with alarm circuits to sense the ac input voltage zero crossings in order to indicate "mains problem". This somewhat overambitious alarm is sometimes used to block the power supply from operation, but more often it is just sent to the powered equipment for a decision of what action to take.	The equipment driven from category 3 units usually only makes a note of the alarm, no further actions taken. If it is a computer or a server unit one may even be able to turn off the alarm altogether in the BIOS setup
4	Pure ac designs with low frequency transformer input circuits. Category 4 units are normally small external units.	May easily be replaced with standard switch mode converters of category 1, which are readily available, running perfectly well from DC 350 V.

Table 2. Power unit categories and consequences for DC operation

VI. ECONOMY

Currently all large server and data centers rely on traditional AC UPS solutions for securing operation during power outage. A major operator of server hotels in Sweden has reported that electricity accounts for roughly one third of the total operating costs over a 5 year period for his server centers.

A qualitative estimation shows that there definitely is a potential for great savings in total cost of operation of data centres by using the more efficient DC UPS. We judge the range to be of 10 to 30 % in savings versus the current ac concepts, see [1], [2]. The amount of electrical energy used for data centres and data processing worldwide has now reached a magnitude where every percent saved in heat dissipation is extremely valuable, see [3].

VII. PERSONAL SAFETY CONSIDERATIONS

Regarding personal safety, direct current has obvious advantages. No doubt alternating current at 50 - 60 Hz is a danger to the life of human beings and animals. Alternating current can cause cramps in the muscles and in the heart. Direct current does not cause cramps nor pose as high a risk of fibrillation as ac. The shock perceived in contact with a dc-cable is an electrostatic shock. The reaction is a reflex movement away from the conductor to break the contact. The possible resulting harm is secondary injuries from falling or bumping against other objects. Burns can occur with both of the current modes.

The influence from electric current on human beings has been described in [4], and [5]:

"It is not the voltage itself that is injurious but the electric current that is propulsed through the body by the voltage.

Alternating current at 50 Hz is particularly hazardous for humans. Already very low current (0.5 mA) may cause discomfort, and higher current level (10 mA) can give rise to cramp, making it impossible to leave hold of a live object. Should the current increase to about 40 – 50 mA there is a high risk of fibrillation and lethal influence already after about a second, and at higher current level even faster."

VIII. CONCLUSION

The Gnesta municipality data centre HVDC UPS has been working in accordance of expectations for more than one year. Connecting and starting the different load objects have been the most tricky task but has been completed successfully. Netpower has shown that most of standard data centre equipment can be safely powered and run from a HVDC UPS system at 350 V. During the year the new UPS concept has shown to be superior in transient suppression, energy efficiency, reliability and power quality.

INTELLECTUAL PROPERTY RIGHTS

The method and system for distribution of standby electric power according to this description is covered by a number of patents in Sweden and US. These are SE516 059, SE516 756, SE517 112, SE529 219, US6498966 and PCT-patent applications no: PCT/SE98/01611, PCT/SE2005/000762 and PCT/SE2007/050343 with John Akerlund and Jan Ottosson as co-inventors.

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