

The Benefits of Superconductor-powered Data Center

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Throughout the last 20 years, no other industry sector has experienced as much growth and value as technology companies. Companies like Google, Apple and Amazon have become global players and are among the highest valued companies worldwide. With the help of technological and communication advancements, our lives have become increasingly interconnected, and more of this interconnection is taking place online.

Data centers are at the heart of modern commerce. They are in essence structures that use large amounts of power to store, relay and transmit large amounts of information across the world. Located in regions with access to sufficient power, data centers need a high reliability to ensure 24/7 uptime. At this moment, there is currently 1.3 GW of IT power installed in Germany and an additional 2 GW will be installed by 2029 [1]. According to the study by the Germany Data Center Association, this increase equates to an investment of around 24 billion € in the next 5 years.

The power per rack has been increasing steadily throughout the years. With the surge of AI technology, it is looking to increase further. Power ratings of 200 kW per rack are envisioned in the near future. Dealing with a thermal load of this caliber is not possible with conventional fan-cooled servers, so data center builders are switching to liquid cooling. The new energy efficiency law in Germany is additionally pushing data center operators to become more efficient. Power usage effectiveness (PUEs) of 1.2 and a heat reuse of 20% will become mandatory for new data centers by 2030.

Meeting the efficiency goals with conventional AC-technology is challenging data center operators. To increase efficiency with conventional (copper and aluminum) technology, the voltage is increased to reduce the operating current and the resulting heat generation. Concepts are emerging to use MV (medium voltage) cables inside the data center and moving the UPS (uninterruptable power supply) to MV as well. This will increase the size and cost of data center and connected converters.

Reducing the cooling power and letting the hardware operate at higher temperatures is another way to decrease PUE. This trades higher efficiency in the short term for reduced lifetime of IT hardware, not a sustainable solution. Liquid cooling, either immersed or direct to chip, is another alternative, as it is more efficient than fan-cooling servers and offers higher grade heat for heat reuse.

Current data centers have a power density of around 10-20 kW/m², 30-40 kW/m² for high performance computing (HPC) data centers. They traditionally use an AC power distribution system, while back-up batteries and servers operate on DC (direct current). This mismatch results in multiple voltage levels, various AC/DC conversions and additional heat generation that needs to be dissipated. The MV is supplied by the attached utility grid, then transformed down and distributed to the power distribution units (PDUs). From here the power is routed to the individual RPPs (remote power panel) and finally rectified to DC in the rack's power shelves. From the MV connection, the power goes through three transformations and each step has a not-so-insignificant power loss.

However, there is a way to eliminate the transformation losses and decrease the electric losses at the same time: by using DC distribution voltage and superconductors. A DC power distribution system will make conventional, compulsory infrastructure obsolete and reduce the amount of cooling power required, which will increase efficiency and reduce material costs.

The Solution: the Superconducting Data Center (SCDC)

Superconductors have no DC-resistance and extremely high current densities, which means the distribution voltage level can be set at the voltage of the UPS (380 V). Since the IT hardware runs on DC anyway, a single DC-DC power shelf supplies the rack with power. The differences in the two infrastructures can be seen in Figure 1.

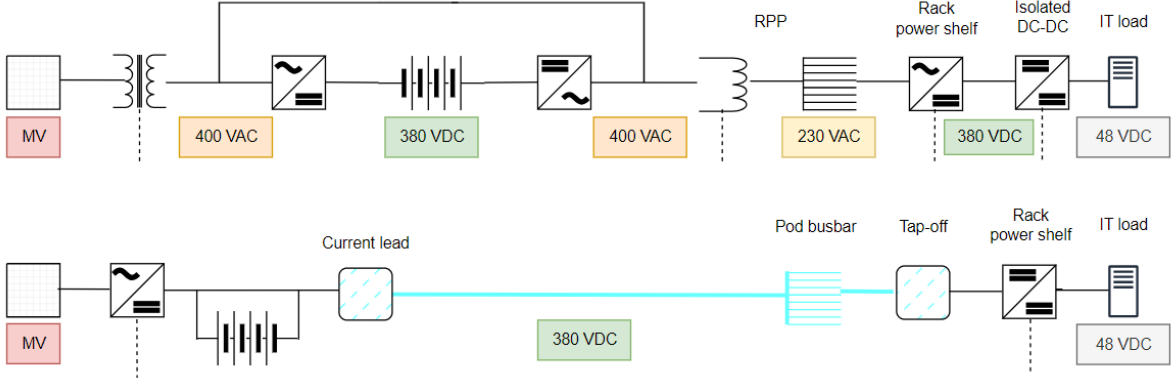


Figure 1 Top: a conventional AC data center infrastructure. Bottom: infrastructure of a superconducting data center.

The cooling is done via a current of liquid nitrogen (LN2) that is pumped through the distribution line to the tap-offs and back to the cooling machines. Assuming a liquid cooling of the racks, a heat reuse can be implemented that reuses the heat from the IT-hardware as well as the heat from the cooling machines, allowing for incredible efficiencies. The reduction of components also increases the reliability of the system, as less components translate to less failures.

These advantages are brought together in the SCDC. The concept consists of pods that house 32 120-kW racks, 16 per aisle. Two superconducting distribution systems feed a total of 14 pods resulting in a total power of 55 MW. Each superconducting distribution is designed to supply the whole data center with power, establishing a power redundancy. Inside the pods, a tap-off box connects directly to the racks. The 380 VDC distribution voltage is stepped-down by a DC-DC power shelf.

SCDC combines this electrical infrastructure with sustainable building materials of the Wooden Data Center and liquid cooling system that uses state of the art adiabatic coolers. A heat reuse will be in affect and the heat output of the cooling machines will be integrated. This increases sustainability throughout all scopes.

Comparison to conventional AC system

Comparing the systems can be done with using rough order of magnitudes. First off, the AC-system will include 5 % conversion losses [2], due to the AC-DC conversion in the UPS and power shelf converters. Two different modules will be defined, the distribution inside the pod and the distribution to the pods.

The CAPEX of the AC system will consist of copper conductor costs. The size and weight of the copper will be calculated with the distribution length and by assuming a current density of 1.2 A/mm². This not only calculates a total weight, but also the electrical resistance, which will be used to estimate the electric losses. The voltage of the AC distribution to the pods will be 400 VAC and inside the pods at 230 VAC. A price of 15 €/kg will be assumed for the copper conductors.

The superconducting system will consist of four main parts: the HTS conductors, the cryostat, the current leads/tap-offs and a cooling station. The heat leak of the superconducting distribution system is assumed to be 2 W/m, with the current lead and tap-offs needing 50 W/kA cooling power. The cooling demand is added together and divided by the efficiency of 7%, to estimate the electricity cost at room temperature. A current lead will be estimated at 105,000 € and a tap-off at 10,000 €. Cryostat cost will be estimated at 500 €/m, HTS costs at 150 €/kAm.

Table 1 Cost comparison of electrical infrastructure between a purely copper-based and superconducting system as described in the SCDC.

Conventional AC Data Center		SCDC	
OPEX			
Electric losses for 14 pods	316 kW	Cooling power for 14 pods	147 kW
Electric losses for 2 distribution lines	1,242 kW	Cooling power for 2 distribution lines	537.2 kW
Transformation losses	3,450 kW	Transformation losses	- kW
Total electric losses in the data center	5,007 kW	Total Cooling power	684.2 kW
Electricity Expenses	7,715,000 €/a	Electricity Expenses	1,055,000 €/a
CAPEX			
CAPEX for 14 pods	4,200,000 €	CAPEX for 14 pods	5,164,674 €
CAPEX for 2 distributions	4,000,000 €	CAPEX for 2 distributions	9,294,779 €
-	-	Cooling Machines for 684.2 kW	1,202,026 €
Total	8,200,000 €	Total	15,662,000 €
Payback			
1.12 Years			

Compared to a conventional AC-system, there is an increased CAPEX consider. The cooling station, thermal insulation and superconductors result in a higher upfront cost than a conventional copper system. However, the OPEX is much lower, resulting in a payback time of under two years. The superconducting distribution will also save space, allowing for unprecedented power density inside the data center and reducing land cost.

The simplified DC infrastructure is another added benefit, transformation losses inside the data center are avoided. There are multiple converters and power shelves that can step-down this voltage to supply the IT equipment. Furthermore, this voltage level is in line with the recently created norm for DC-power cables [IEC TS 63236]. The DC grid can be expanded to include PV arrays, electrolyzers and fuel cells. These are components that are inherently DC. Wind power can also be included on a DC basis. Wind turbine power trains have a DC rectification stage before converting to 50/60 Hz AC. An implementation at this rectification stage would save further transformation losses. Sourcing renewable energies within this grid will be highly efficient and operators can consider implementing an “energy as a service” system. The low operating costs would make it more profitable than conventional counterparts.

Exceeding the Limits of Conventional Technology

Due to recent developments rack power inside the data center is increasing and taking the conventional technology to its limits. This is where superconductors can enable and improve data centers. The SCDC concept was described, and a cost estimation was done comparing the system to a conventional data center. It was shown that superconductors can eliminate the electric distribution losses inside the data center and enable high rack power without bringing medium voltage into the data center.

There are even more benefits. Scalability is a major characteristic to consider. The higher the power, the more economical a superconducting data center will become. Including renewables or expanding the superconducting grid to local prosumers will generate even more value. The power density of the superconducting distribution and liquid cooling will allow high power densities inside the white space. The Wooden Data Center design and connected renewables will create a net-zero data center. All these advantages show that superconductors possess a game-changing solution to the challenges of the data center industry.