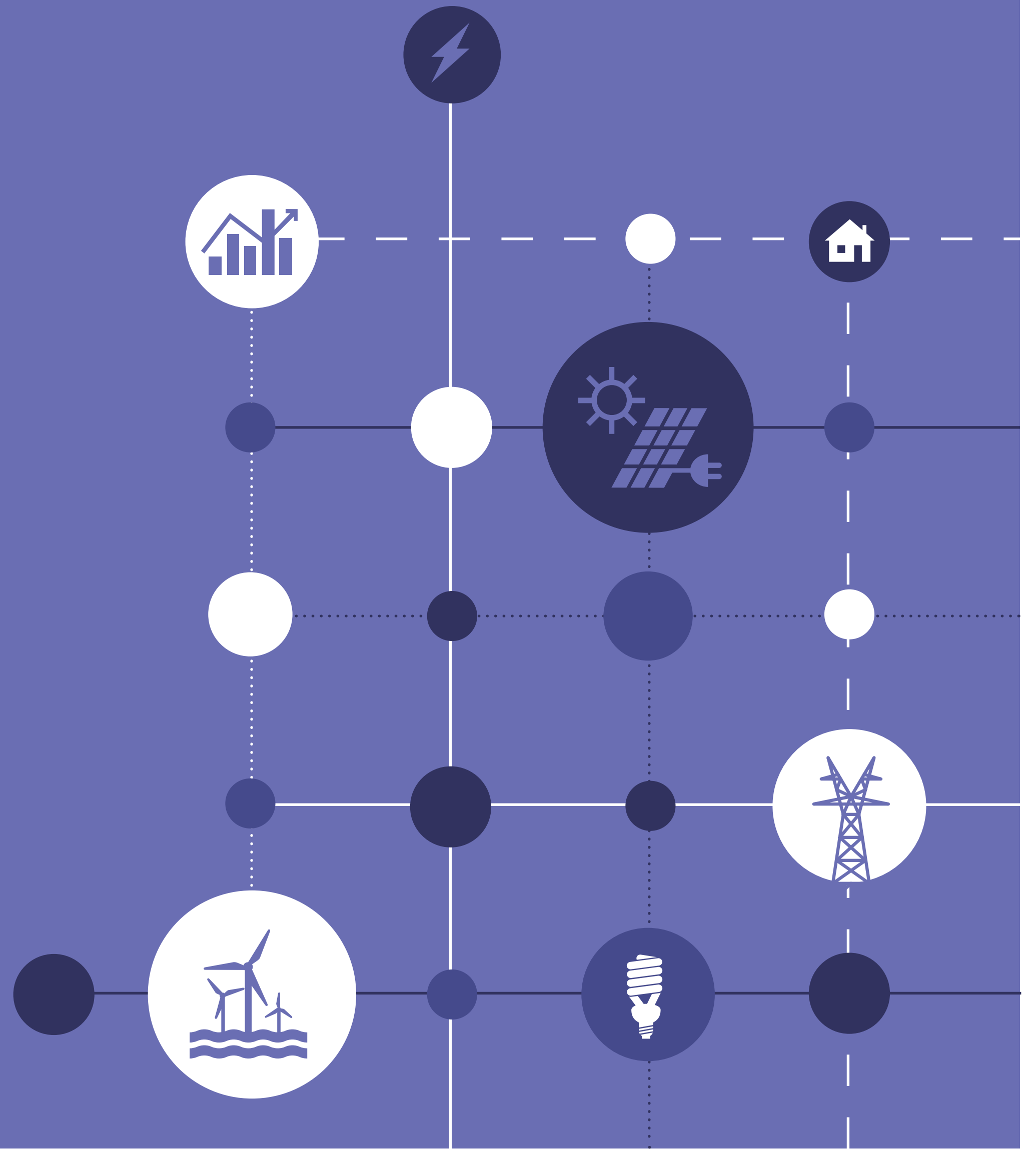
Five minute guide

DC Power



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Historical background

Direct current (DC) is a continuous flow of electricity in one direction through a wire or conductor. DC is created by generators such as fuel cells or photovoltaic cells, and by static electricity, lightning, and batteries. By convention, electric current flows from a high to a low potential; for example, in a battery, from a positive to a negative pole.

The "War of Currents"

Early 20th Century, power systems were developed as isolated networks looking after local needs. But as the demand for electric power and transmission distances grew, voltages had to be raised to maintain efficiency, and networks required interconnection for reliability.

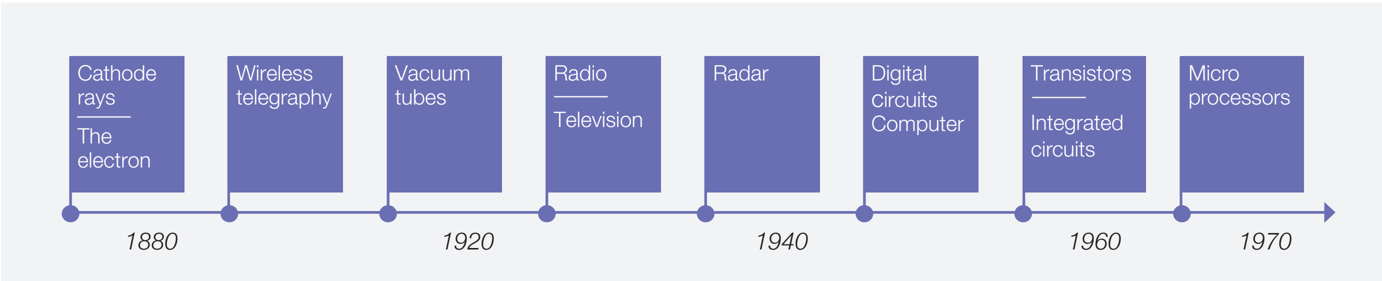
DC systems were constrained due to the complexity of motor and generator design and non-availability of equipment for voltage transformation. Tesla's invention of the induction motor simplified the design of machines for the majority of industrial applications. This led to the dominance of alternating current (AC) over DC for generation, transmission, and to a large extent the utilization of power. In spite of all this, DC continued in use for variable speed motors (for example, for city railways and rolling mills that required better controls) and for electrochemical processes such as electroplating and electrolysis.

DC transmission could not be realized without a sizable loss of power. The solution was to generate AC power, transmit it at higher voltages, and convert it to the desired DC voltage level near the point of use when required. Initially, rotary converters were the only means available for conversion from AC to DC. Rotary converters were relatively expensive and required regular maintenance.

Despite a vigorous campaign against the adoption of alternating current, Edison could not overcome the shortcomings of his DC system for large distribution networks. AC won out, and today all utilities generate, transmit, and deliver electricity in the form of alternating current.

But while AC was perfectly adequate for the conditions of the day – indeed for much of the 20th century – the needs of the 21st century are exposing its limitations. The problem of DC voltage transformation has been solved with power electronics and the number of devices requiring DC power has increased dramatically with the expansion of digital technology. **Today it is not a question of AC versus DC, but of AC and DC.**

Increasing end use of DC



DC applications

Several potential benefits are driving new interest in DC power delivery systems in the 21st century.

The majority of progress in developing DC-based technologies has occurred at either the high- or low-voltage level. At the moment it only makes economic and technical sense at the two ends of the power chain where design standards are already established:

- *Continental transmission* where very long transmission distances are involved (EHV, more than 200kV)
- *Locally within buildings* (LV: 380V and ELV: USB, Power over ethernet and lighting systems)

Microgrids and building scale nanogrids are an emerging application due to advances in equipment and a need for more intelligent energy systems at the edge of power networks.

Data centres

Simplify power system and reduce conversion losses within data centres.

Micro-grids

Enhance micro-grid system integration, operation and performance by making multiple sources of supply easier to connect and operate.

Transport

Future transportation will be mainly electric: hybrid, or battery EV across personal and public transport and commercial fleets.

Lighting

Lighting installations are adopting DC supply to achieve benefits of smaller luminaires with higher performance (e.g. flicker free dimming).

Embedded generation

Distributed generation systems frequently produce DC power (e.g. PVs, wind turbines).

Power electronics

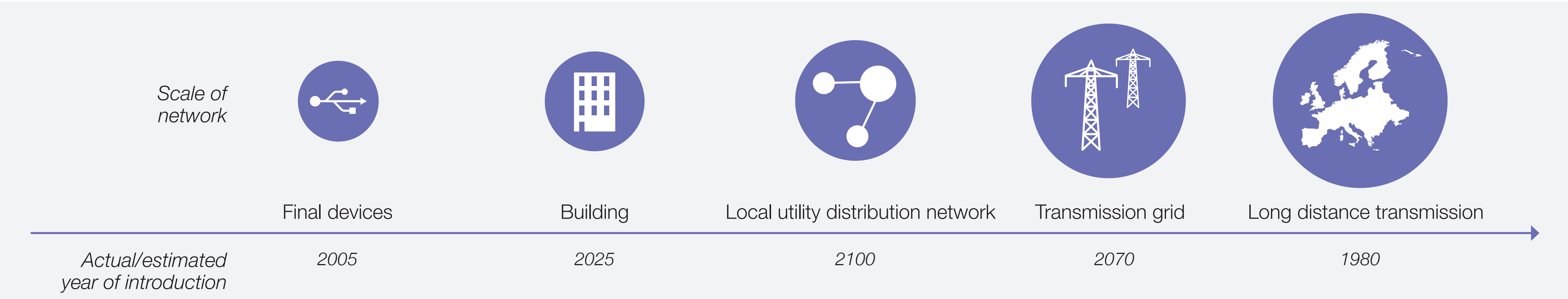
Increasing quantity of DC electronic equipment.

Low cost electronics has replaced traditional lighting sources and enabled efficient variable speed control of induction motors within equipment.

Storage devices

Devices such as batteries, flywheels and capacitors store and deliver DC power.

Use of DC in electrical networks



Opportunities and challenges

There are advantages and challenges associated with the introduction and usage of DC. For new markets, like electric vehicles and photovoltaics, it is very natural to introduce DC. For established markets like buildings, DC networks will become popular when the technical and/or cost advantages combine and become compelling enough to outweigh the challenges.

Key benefits
Modern electronic loads are all inherently DC loads. Even appliances that require different voltage levels interface better with a DC supply, because of the elimination of AC-DC conversion (efficiency, materials and space benefits.)
With DC power, there is no reactive power loading the lines, there is no need for phase synchronization and no harmonic current mitigation required in the DC installation. This reduces the complexity of engineering networks with multiple sources of supply and helps to improve system efficiency.
Distributed generation systems, such as photovoltaic cells and fuel cells, and advanced energy storage systems, produce energy in the form of DC power so it is more efficient and cost effective to connect with DC than converting to AC.
DC power delivery can enhance micro-grid system integration, operation, and performance.
High Voltage DC is economic and reliable and also economic for transmission distances in excess of 500km.
Installations are increasingly controlled through digital means rather than physical switching of power. Where devices (such as luminaires or motors) are infrequently used the standby energy in power converters can be a significant proportion of overall energy use (in adverse conditions more than 50%). DC-DC power converters consume far less standby power than conventional AC-DC converters.

Addressable challenges
Business case for DC power delivery in established markets is not yet demonstrated in a completed installation. It is likely that the business case will be strengthened when coupled with other technologies such as network discovery, powerline comms, metering/control, bidirectional flow, commissioning and error services which reduce operating costs and improve reconfigurability of installations.
Safety and protection standards and equipment need to be developed.
Common practices for design, installation, and maintenance need to be established.
High performance applications require fast-acting DC circuit breakers.
Technologies to support grid controllers and network management need to be developed and standardised.
To mitigate transition cost, appliances will need to be suitable for both AC and DC supply with agreement of technical standards (voltage and connector).

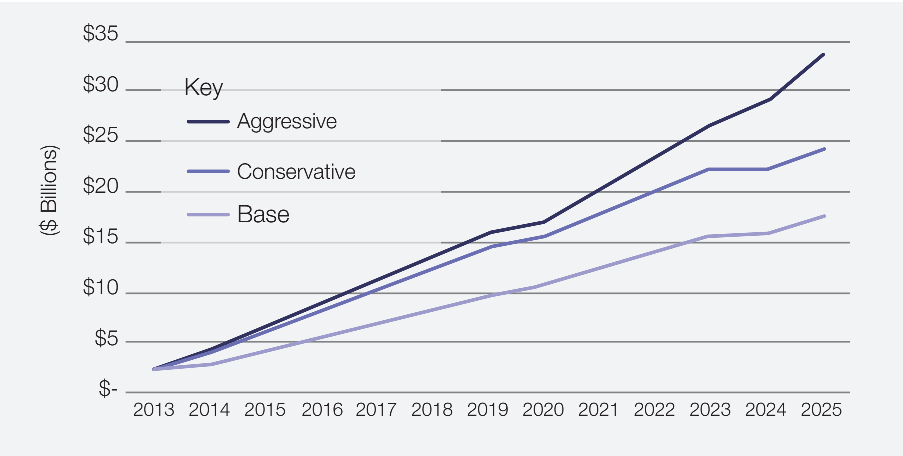
DC market

The number of applications in which DC makes sense is increasing. The following pages of this guide provide insights into a selection of these applications.

Edison's original vision for a system that has DC generation, power delivery, and end-use loads may come to fruition – at least for some types of installations.

However the market for DC distribution networks is not a single, cohesive market. Rather, it encompasses several disparate opportunities—telecommunications towers, data centers, grid-tied commercial buildings, and off-grid military networks—that will respond to specific market dynamics.

Total DC Distribution Network Vendor Revenue by Scenario, World Markets: 2013-2025



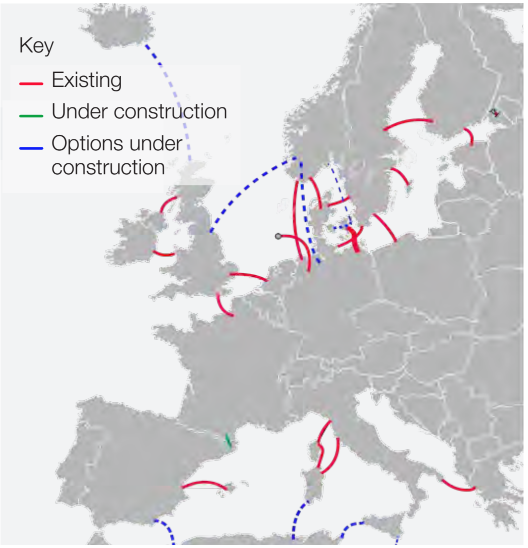
Source: Navigant Research

HVDC transmission

Although in Edison's time, direct current was impractical for transmission beyond the distance of a mile, today high-voltage direct current (HVDC) can transmit bulk power over very long distances and enables interconnection of incompatible power networks.

Since the 1950s, HVDC transmission has been in practice worldwide as an effective means for transmitting bulk power over long distances. Since the first use of mercury arc valves to modern solid state IGBT devices at present, HVDC technology has advanced significantly achieving cost effective bulk power transmission and becoming the backbone of future power networks.

HVDC interconnectors



HVDC in a nutshell

HVDC provides instant and precise control of the power flow. Manual or automatic control determines the required power flows via the link.

The HVDC link enables secure and stable asynchronous interconnection of power networks that operate on different frequencies, or are otherwise incompatible. It also provides fast response to change in voltage and frequency at either end.

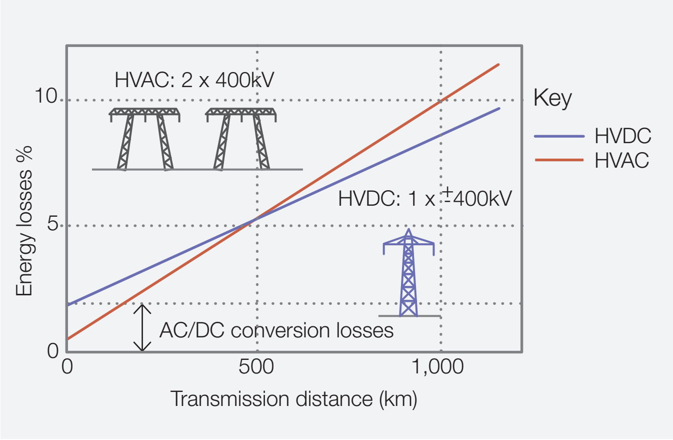
HVDC transmission requires a converter station at each end to form the terminal equipment for the transmission line. In AC transmission this conversion is not required.

HVDC transmission does not contribute to the short circuit current of the interconnected AC system. As a result there is no impact on the existing transmission infrastructure.

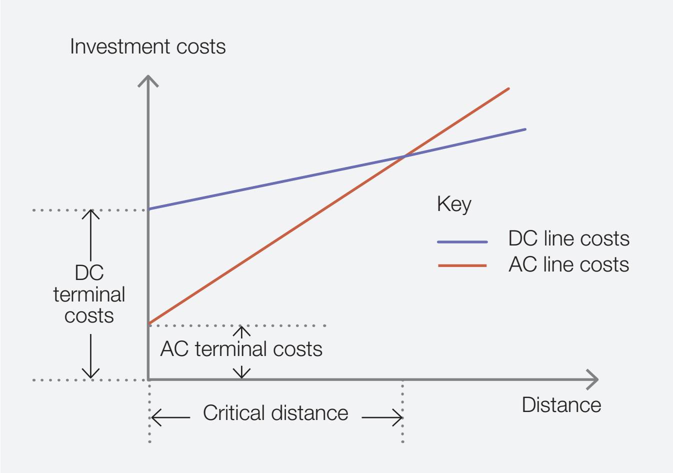
HVDC transmission schemes have less environmental and visual impact and require reduced right-of-way and less space compared to HVAC.

The HVDC market is rapidly growing. New innovation should provide choices, reduce cost and increase the viability and commercial certainty of future HVDC transmission projects.

DC power: lower losses for longer distances



Critical distance at which DC becomes more cost effective



Source: Special Report 60 years of HVDC, ABB

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Road transport electrification

The electrification of road transport is seen by many as a potential game-changing technology that is having a significant influence on the future cost and environmental performance of personal individual mobility as well as goods transport.

Battery electric vehicles

Electric vehicles deliver zero tailpipe emissions and have the potential to offer solutions to the air quality challenges of urban mobility.

Chemical energy is stored in rechargeable battery packs which deliver their electrical output as DC.

DC fast charging

DC fast charging is mitigating the fear of "range anxiety".

Standard electric vehicles use an onboard charger to convert AC from a wall charger to DC that's stored in the battery pack.

Fast charging stations can impart a 50-percent charge, which equals to about 170 miles of range in as little as 30 minutes with a rate of charge up to 400kW. Vehicles will be equipped with a direct DC connector to take advantage of these stations.

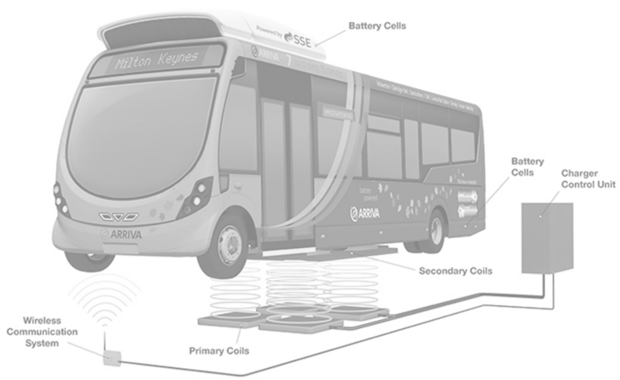
Autonomous vehicles

Driverless cars resolve the practical limitations of today's non-autonomous electric vehicles, including traveller range anxiety, access to charging infrastructure, and charging time management.

Wireless charging

Opportunity charging offers booster charges during the day.

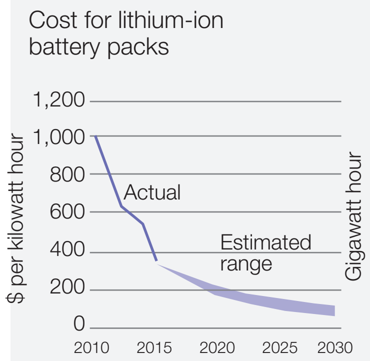
Wireless charging has been applied in real life context and fully operational environment for electric buses, whose cycles are very demanding and unusually large batteries are required.

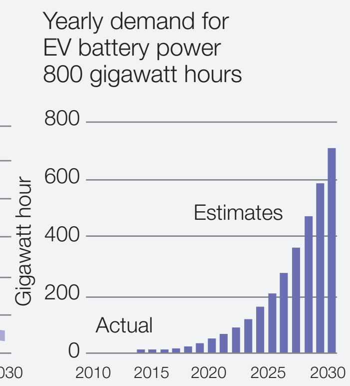


It's all about the batteries

Each electric vehicle has tens of kilo-watt hours of energy stored in its battery packs, and, when fitted with bidirectional power converters that have the ability to link with the grid, each will eventually serve as a load, power source, or distributed energy storage that can support the grid. This will improve system efficiency, use of low carbon sources, stability, and power delivery reliability and security.

Batteries make up a third of the cost of an electric vehicle. As battery costs continue to fall, demand for EVs will rise.





Source: Bloomberg New Energy Finance

System safety and integration

The technical challenges that, over a century ago, made DC more difficult to distribute than AC have been solved with developments in power electronics. Most installations now employ a hierarchy of power supply arrangements. In certain scenarios, DC technology offers simplicity, safety and cost reduction benefits.

Wiring architectures

As the number of electronic sensors and actuators in buildings has increased, and their cost has reduced, the cost of connecting them to power is becoming a significant, sometimes dominant, proportion of overall installed cost. Therefore there is a strong economic incentive to reduce the cost of wiring systems and power conversion (rectifier and voltage transformation) that are installed local to devices.

Safety

Electricity is associated with some dangers to humans and livestock. However, the physiological effects depend on the means of contact, environmental conditions (e.g. presence of water) and voltage level. Notably AC and DC have different effects. AC current is more likely to cause ventricular fibrillation whereas DC is more likely to cause asystole. People are already familiar with handling laptop computer and other personal device chargers (notably USB), and the opportunity exists to extend DC power for local distribution within buildings: for example lighting tracks and exposed small power conductors in floor and wall finishes. In dry conditions, DC conductors are considered safe to touch up to 60V, whereas the safe-to-touch limit is only 25V for AC circuits.

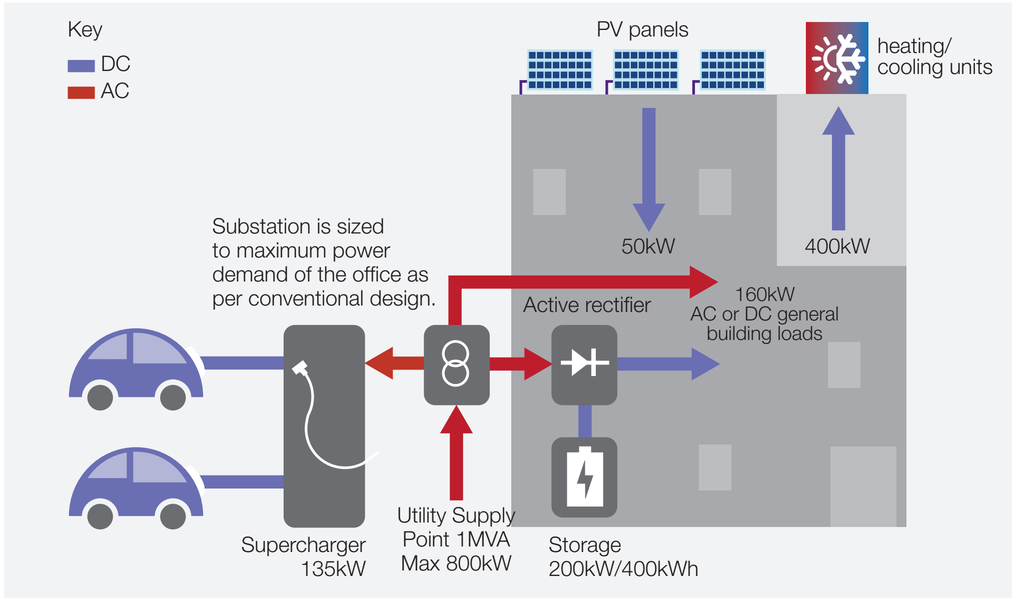
Retrofit

There have been field trials in the UK market of retrofitting DC energy supply to existing wiring systems in houses. The system integrates a battery store with energy efficient lighting and extra low voltage DC power outlets.

Voltage levels for building applications

Voltage	Application		
≥465V	Direct interconnection with three-phase, 400V AC grid		
380-400V	Standard in the data-centre industry		
350V	Current/OS standard		
325V	Minimum modification required for loads with input rectifier		
230V	Compatibility with pure resistance loads		
120V	Limit for extra low voltage DC, electric shock protection is basic insulation only		
60V	Safe DC. Limit for DC conductors exposed to touch in use		Safe DC
48V	Standard in telecommunication industry		
25V	Safe AC. Limit for AC conductors exposed to touch in use	Safe AC	
24V	Emerge Alliance Occupied Space Standard		
20V	USB type C (implementing USB-PD)		
12V	Standard in automotive industry		
5V	USB legacy		

A hybrid AC/DC distribution system for commercial building applications



DC local power distribution

There are three basic approaches to power native DC devices, with two involving DC distribution. Many buildings contain two or even three of these architectures in different places.

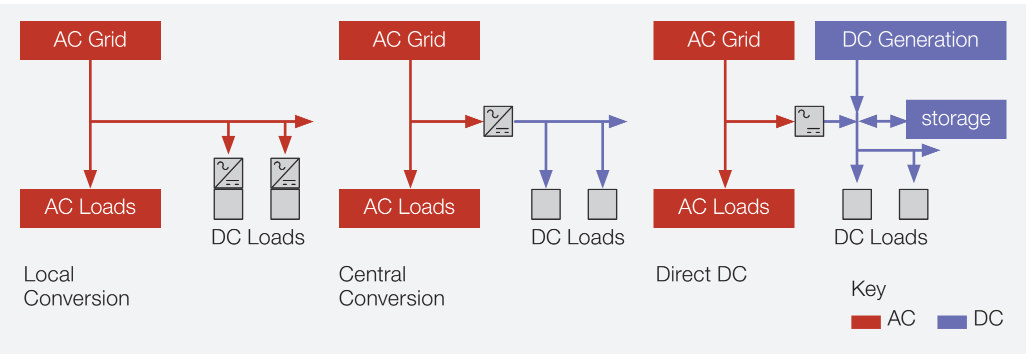
> Savings estimates from direct DC vary in the range 2 to 14% depending on application context and baseline assumptions.

Local conversion of appliance distributes AC power to all electrical devices with conversion to DC occurring inside of each DC device and no alteration or addition to the building wiring.

Central conversion moves the location of the AC-DC conversion to a central rectifier and distributes DC to end-use devices. Central conversion can achieve greater technical performance and convenience and can reduce the **standby watts** drawn within final devices. Typically, there will be a small and efficient DC-DC final conversion step at each device.

Direct DC architectures are able to incorporate local generation and local storage into the DC system. These systems enable power to flow from generation to end use-through storage as needed, without ever having to be converted to or from AC. Savings estimates from direct DC vary in the range 2 to 14% depending on application context and baseline assumptions.

AC/DC grid topologies

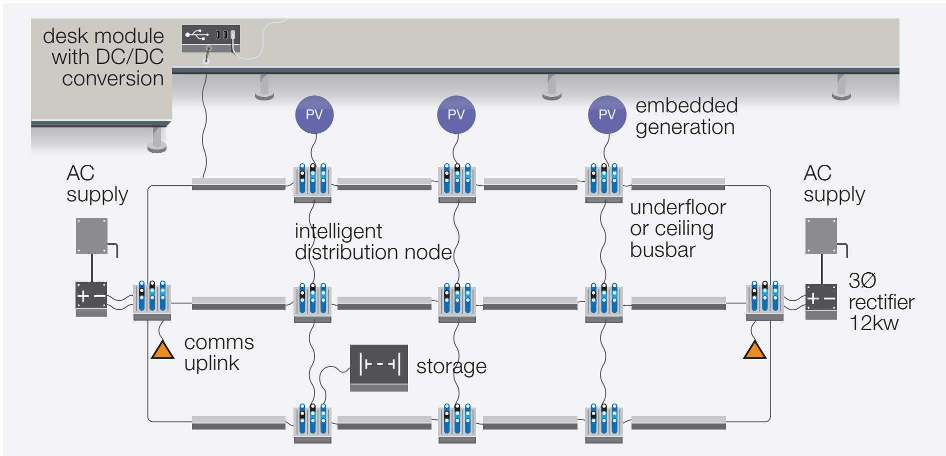


Managed distribution

Managed power distribution of DC is possible either with the addition of communications with power on the same cable, or with wireless communications. Power and communications is already implemented in at least three standard technologies: USB, Ethernet, and HDBaseT.

Enhanced functional features within the distribution infrastructure can provide a stronger business case than DC power alone: demand response, fault-resilient mesh wiring, live modification, topology discovery, system health check, distributed metering and auto-configuring electrical protection all have substantial value benefits for facilities manager and building occupier.

Possible design for managed power distribution in offices



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Reshaping buildings

DC power fits within the wider agenda of reshaping buildings. It provides promising opportunities for reshaping energy in buildings by its application with data analytics, communications, demand response, reconfigurability and novel commissioning approaches. These characteristics combined in a new distribution system will not only yield operational benefits but will reduce the need for electricians and other skilled labour to adapt installations as needs change. As already mentioned an increasing fraction of electrical loads in buildings is natively DC while a large portion of the remainder of loads in buildings could readily be converted to DC at equal or greater efficiency than with AC.

Case Study: The Circular Building

The Circular Building is an exploration by Arup, Frener & Reifer, BAM and the Building Centre of circular economy principles in the industry.

The electrical system is modular low voltage and off-grid, facilitating future flexibility and ease-of-maintenance. Nearby all of the installation operates from a direct DC system. An external battery cabinet houses an AHI battery operating at 48V nominal with a capacity of 100Ah sufficient for several hours autonomous operation. The battery is supplies a series of mechanical and electrical loads including lighting, small power, fan units and controls.

All images: The Circular Building

Future office workplaces

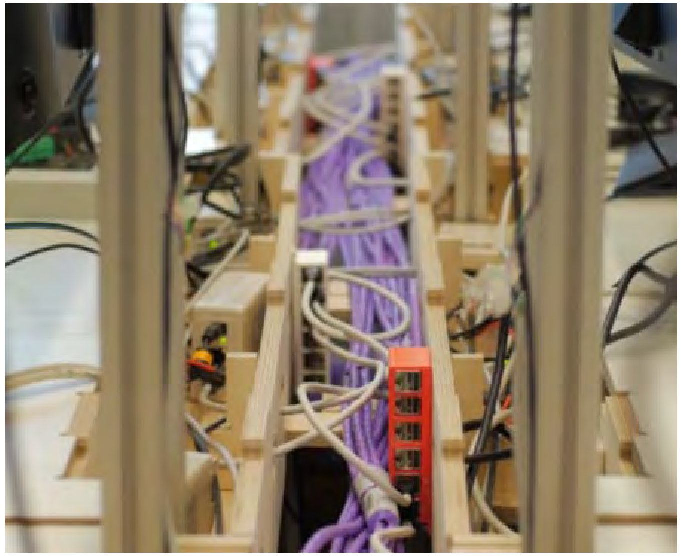
Business are looking for creative design of office workspaces to improve efficiency, flexibility and resilience. DC power can play a key role in the workspace evolution by pushing boundaries further and faster with new ways of connecting the power. The use of DC in workspaces is growing, primarily at the very edge of the building power-distribution tree offering a rational, convenient, safe, consistent and economic way of connecting multiple electric devices in office accommodation.

Case Study: All about the Desk

The 'All about the Desk' research project is an Arup initiative towards changing our building projects in response to technology innovation, specifically open, web compliant approaches to sensing, actuation, and interaction, thereby improving end user experience and reducing environmental impact.

Buildings have multiple data systems (IT, HVAC, Lighting, Security, Fire, VT, AV) which often have limited interoperability due to a lack of common well-structured languages and protocols. By providing new approaches to power supply together with an open controls approach based on scalable web technologies, the integration of simplified, adaptable systems at lower cost is enabled. Benefits such as reduced time for resolving FM issues could be maximised by introducing more open integrated controls.

All about the Desk



Sky Central

All about the Desk

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