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Technical considerations for d.c. installations

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The re-emergence of d.c. power systems

The public supply electricity supply in the European Union has been harmonized at a nominal 230/400 V 50 Hz a.c. (or 230 V 50 Hz a.c. three-phase, where one phase of a three-phase system is earthed), with a tolerance of + 10 %/- 6 % (see Table 1), and many member countries have been using similar voltages for upwards of 50 years. The skills, techniques, equipment, and products have therefore been geared towards such supplies for quite some time. Emerging technologies, combined with the subject of energy efficiency, are leading designers to consider wider use of d.c. circuits within electrical installations of buildings in a variety of applications including services to data centres, solar photovoltaic installations, energy storage, and LED lighting.

Table 1: Supply voltages in the harmonized public low voltage supply to BS EN 0160:2010+A1:2015

Supply type	**Nominal a.c. voltage**	**a.c. voltage range (tolerance +10 %/-6 %)**
Single-phase	230 V	216.2-253.0 V
Three-phase (star-point neutral)	400 V Line to Line (230 V Line to Neutral)	376.0 - 440.0 V (216.2 – 253.0 V)
Three-phase (one line as neutral)	230 V Line to Line (230 V Line to Earth)	216.2 – 253.0 V (216.2 – 253.0 V)

One of the primary reasons for the historical use of a.c. in the public electricity distribution system was the ease with which the voltage could be increased, using a transformer, to reduce losses in long-distance power transmission lines, and subsequently decreased again using a transformer local to the point of use. With modern power electronic techniques, increasing and decreasing d.c. voltages is relatively inexpensive and commonplace, for both low- and high-power devices. This is achieved with d.c. to d.c. converters, which use high-frequency switched-mode circuitry. When arranged to increase the voltage without the use of a transformer, these may operate in a similar manner to the switch, condenser, and coil arrangement that drives spark plugs in a petrol car. Switch-mode converters contain switching transistors and capacitors with inductors and/or transformers, and may even include galvanic isolation. The efficiency of a transformer increases with frequency, as less copper is required in the windings; hence, d.c. to d.c. converters can have a better energy efficiency performance than a.c. transformers, and a.c. to d.c. converters.

The requirement to use d.c. power arises in a wide variety of situations relating to current technologies for energy generation and electronic devices. Solar-photovoltaic generation, for instance, inherently delivers d.c. power. Various technologies that convert energy from the elements (wind, solar, tidal power) do not provide consistent power as the energy source itself is not consistent. To store this power requires d.c. technologies. Energy losses are involved whenever d.c. is converted to a.c. and vice-versa, so if some of the generated or stored d.c. power can be used without converting to a.c. first, energy savings can be achieved.

There has been a large increase in the use of electronic devices, which by their very nature use d.c. power, such as mobile and smart phones, and other portable devices. Again, there are inherent energy losses in transforming the a.c. mains into the extra-low voltage d.c. required by the device, which can be as much as 20 % depending on the adaptor used. The adoption of Universal Serial Bus (USB) and similar charging systems for portable devices has led to a demand for user socket-outlets operating at d.c., which is currently being filled by a multiplicity of after-market transformer-adaptors, many of which are not energy efficient.

In the case of commercial and industrial computing devices, such as those used in data-centres, research has shown that significant energy savings are available where the supplies to equipment racks that house network equipment and servers is operated at low or extra-low voltage d.c. LED and other types of energy-efficient lighting are beginning to enter mainstream, and whilst it is possible to manufacture devices operating from a standard a.c. light fitting, it is far more energy efficient to power them from a d.c. source.

Designers, installers and maintainers may be less familiar with low voltage and extra-low voltage d.c. power. This article discusses some of the challenges that designers, installers and maintainers, are faced with, and introduces the following publications from IET Standards: The recent IET Code of Practice for Low and Extra Low Voltage Direct Current Power Distribution in Buildings; and the accompanying IET Standards Technical Briefing: Practical considerations for d.c. installations which is due to be available soon.

Considerations for d.c. circuits in buildings

Among the chief considerations for the wider use of d.c. circuits in buildings is selection of appropriate protective devices, switchgear, and accessories. Many of the standards for accessories and protective devices currently common in the industry are a.c. only, and products complying solely with those standards may not be suitable for d.c. systems. Switchgear, plugs and socket outlets used with d.c. systems will be capable of handling and where appropriate suppressing arcing which occurs as plugs are withdrawn or contacts open; this does not occur in a.c. systems as the current-waveform crossing zero helps extinguish arcing. RCDs are not, generally, available for d.c. systems at present. High breaking-capacity (HBC) fuses, including suitably-rated fuses to BS 88, are technically a good choice for protecting d.c. circuits. However, in installations such as those for households, it has become commonplace to utilise resettable devices such as mcbs to help mitigate the risks that might arise from the lack of training and specific knowledge of persons in the premises.

Another primary consideration is whether installers and maintainers have the necessary skills and experience with d.c. installations of the kind being considered. Test equipment and fault-finding practices differ slightly with d.c. circuits; appropriately-rated test equipment must be used. Those using the equipment need to be aware of the limitations of some a.c. equipment settings on d.c. systems. For example, a multimeter on an a.c. setting may read zero if used on d.c. circuits, giving the false impression of absence of voltage. It is important to ensure that voltage testers/indicators used for “proving dead” are suitable for both a.c. and d.c. operation.

A voltage indicator from Martindale Electric

Among the considerations for those commissioning and maintaining installations is that of identifying d.c. circuits separately to a.c. circuits, so that appropriate test equipment and working practices can be selected. The basic colour-coding scheme harmonized by BS EN 60445, and included in BS 7671, does not assist installers and maintainers in distinguishing between conductors operating from a.c. and d.c. sources, and at different voltage bands. One example would be that a conductor identified only with the colour blue may be a mains neutral (N), or, in d.c. systems, a conductor which is either a mid-point (M), earthed mid-point (M), positive-earthed (L+) or negative-earthed (L-). A common-sense approach is to provide a means of identifying the function of circuits from over-marking cables and containment in which the conductors run. Alphanumeric marking can also be applied in addition to colour-coding on conductors themselves, and this better-distinguishes the function of the conductor as a.c. (L, N, L1, L2, L3 etc.), or d.c. (L+, L-, M), as well as providing information about the function of the conductor in the d.c. system (e.g. a conductor coloured blue, and labelled L+, is clearly distinguishable as a positive conductor in a positive-earth system).

Where the supply voltage is 200 V or above, the Plugs and Sockets (Safety) Regulations apply to plugs and socket outlets serving equipment for domestic and similar use. This legislation mandates the use of the BS 1363 plug and socket for the majority of applications; these are currently specified for a.c. installations only.

Designers should consider the impact of d.c. protective and functional earthing conductor currents. Since d.c. earth currents flow in predominantly one direction, electrolytic corrosion of structural steelwork that is buried or in contact with the ground, or earthed metalwork of buried services, may occur. This can be addressed by the selecting how the d.c. source of supply is earthed (e.g. selection of mid-point earth), and considering which means of corrosion prevention may be applied.

Extra-low voltage d.c. systems, whilst often providing a good solution to protection against electric shock, are not free from electrical safety hazards, and provisions of the Electricity at Work Regulations 1989 still apply. Where high current ELV supplies are used, faults can often lead to arcing and heating, and protective devices may fail to operate under certain conditions. Suitable fused test leads and instruments are recommended for testing and fault-finding.

Fixed battery installations should be designed to comply with the requirements of BS EN 50272-1 and BS EN 50272-2 along with BS 7671.

Another consideration with lower voltages is the impact of voltage-drop. At 300 V d.c., the maximum length a cable may be expected to carry its rated load current (without correction factors), to achieve a voltage drop less than or equal to 8 %, is in the region of a few tens of metres As with a.c. circuits, this assumes that circuit protection performance permits this distance. At 24 V d.c., these distances drop to around 3.0 m, 1.5 m at 12 V d.c., and less than 1.0 m at 5 V d.c. It is clear that, for distribution circuits operating at charging voltages of common devices (e.g. USB at 5 V d.c.), or at common battery-voltages, there is a trade-off between the cross-sectional area of conductors required, and the energy saving benefits that such a distribution system might bring. This is illustrated in Table 2 (see the PDF here) which shows the absolute maximum distances before 8 % volt-drop, for various cable types at a nominal voltage of 5 V, which is commonly used to charge mobile devices such as mobile phones, smart-phones, and tablets.

Providing power over small cross-sectional area control, data and signalling cables is not new. Audio systems have utilised so-called “phantom power” over a signalling pair for 50 years or more; similar well-established technologies are employed to provide camera power via coaxial cables in closed-circuit television systems. Intruder alarms provide power using multi-core cabling rated 1 A or less Ethernet standards have used cables carrying power for over 25 years, for example in the attachment unit interface carrying power to the medium attachment unit on coaxial Ethernet systems.

Recently, there is an increasing requirement for USB charging, and also multi-purpose device power using Power over Ethernet. This provides some new challenges. Heating is the primary consideration for Power over Ethernet systems. It is worth considering that existing cabling infrastructure may not originally have been designed with power delivery in mind. There are also some proprietary charging solutions that do not comply with the power delivery requirements detailed in the Ethernet and USB standards, and associated product safety standards.

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Conclusion

The industry is likely to observe an increase in the requirements to design, install and maintain d.c. circuits at low voltage and extra-low voltage, and therefore must be prepared to respond to this requirement.

The IET's *Code of Practice for Low and Extra Low Voltage Direct Current Power Distribution in Buildings*, and associated Technical Briefing Practical considerations for d.c. installations (due to be published towards the end of 2015), provide invaluable sources of information to help design, installation and maintenance planning and preparation. They discuss most of the issues highlighted in the article.