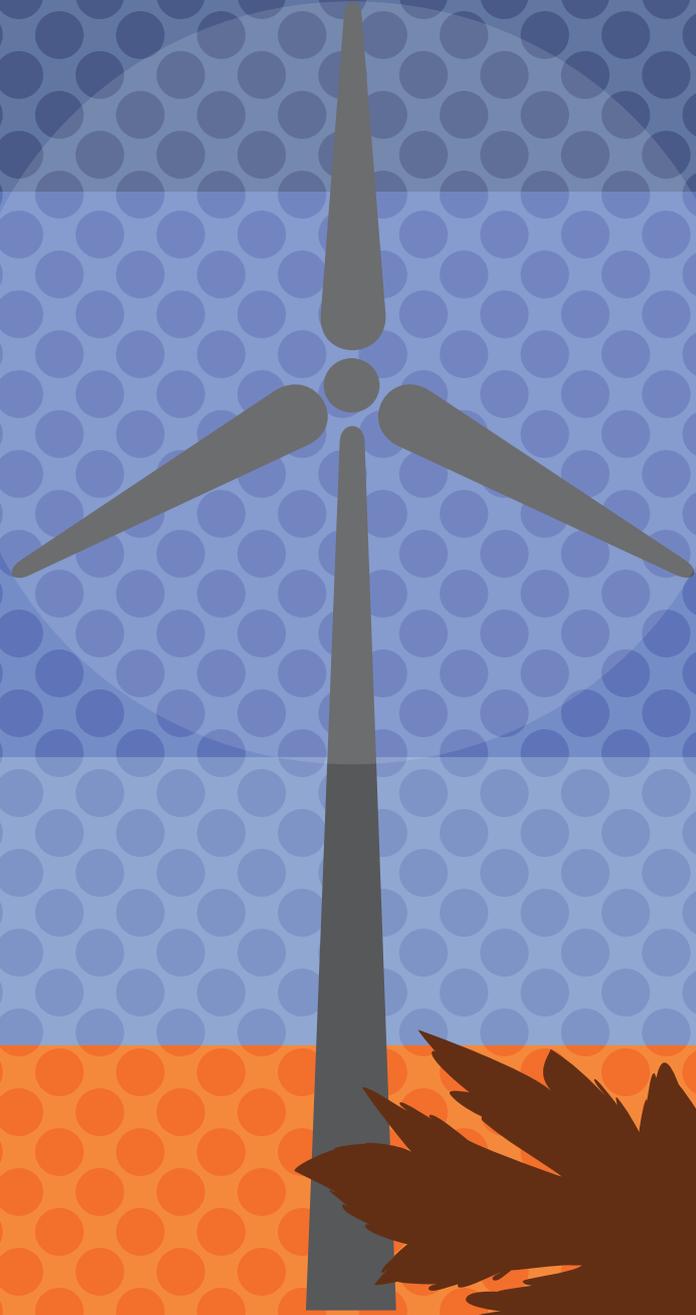


Autumn 2016



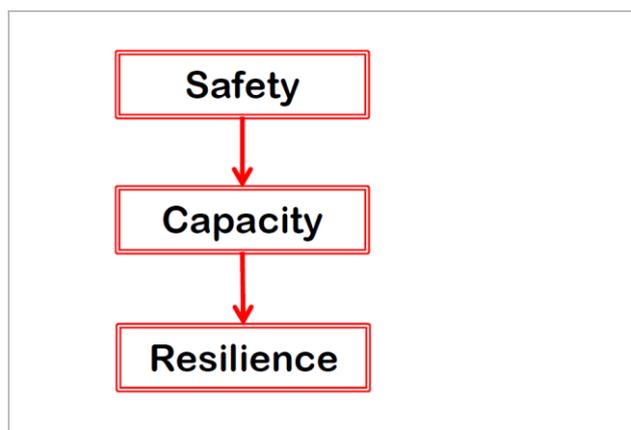
Energy Efficiency in Electrical Installations

A new harmonised document, IEC 60364-8-1 Low Voltage electrical installations – Part 8-1: Energy Efficiency, considers design and maintenance from the context of reducing inefficiency in electrical installations, whilst adhering to safety and operational control. It is likely that IEC 60364-8-1 will be of interest to users of BS 7671 as energy efficiency is of increasing importance to UK electrical installations.

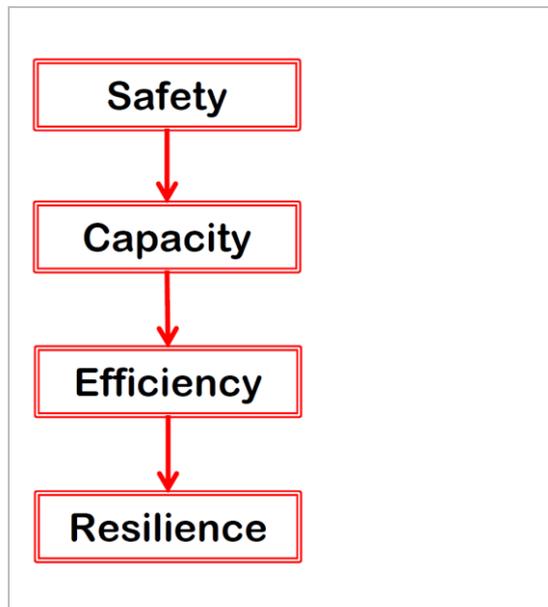
Cameron Steel, author of the recently published [Designer's Guide to Energy Efficient Electrical Installations](#), explains what IEC 60364-8-1 will require from those working in the electrical industry.

Design hierarchy

Ensuring that an installation is safe enough to allow satisfactory operations and has sufficient capacity for existing needs has typically been enough for most installations. Some installations, with safety critical operations, may also have considered resilience to avoid single points of failure and provide system continuity. This means that, until relatively recently, the traditional model of an electrical installation design hierarchy would have been:



Energy efficiency updates the hierarchy of design, and that affects the operation of electrical installations. The traditional design hierarchy will change to this:



There is a change of emphasis to incorporate energy efficiency into electrical installation designs as a prerequisite rather than just as an aspiration. An energy efficient electrical installation has many potential benefits:

- (a) less impact on the environment generally;
- (b) reduces energy losses and hence lowers energy costs;
- (c) uses energy when it is required and potentially at a lower (off-peak) tariff;
- (d) less reactive maintenance due to the adverse effects of heat loss; and
- (e) optimises the electrical system performance throughout its life cycle.

IEC 60364-8-1 considers various factors for electrical efficiency in installations, including:

- (a) the efficient placement of the electrical intake;
- (b) the efficiency of the electrical distribution wiring system;
- (c) the type of controls to avoid wasteful use of loads;
- (d) how and where to provide energy measurement;
- (e) how and what type of loads can be switched off without affecting user safety, function or comfort;
- (f) energy management of electrical systems; and
- (g) the impact of maintenance on the efficiency of electrical systems.

Design requirements

The first design requirement is to stress the importance of understanding the energy profile of both the passive and the active measures taken within the building:

- (a) active: measures for the optimisation of electrical energy produced, supplied, flowing and consumed.

- (b) passive: measures for the choice of parameters of electrical equipment to improve overall electrical energy efficiency of the electrical installation while not affecting the initial construction parameters.

The second design requirement is to reduce energy losses within the electrical installation by two principal methods:

- (a) the location of any energy source (conventional high voltage (HV) or low voltage (LV) intake, local generation, and switchboard) should be optimised where possible.
- (b) the reduction of losses within the installation wiring system is important. Some design criteria will be understood in terms of voltage drops, maintaining power quality and improving power factors. Other considerations in terms of harmonics, typically caused by end user appliances, can cause operational inefficiencies. The issue of harmonics caused by new equipment on older electrical distribution infrastructure is an increasing cause for concern.

Many new installations seek accreditation from BRE's [BREEAM assessment method](#), Leadership in Energy and Environmental Design (LEED) or similar benchmarks. The IEC standard is a design framework for a more energy efficient electrical installation. A client can stipulate, at the design stage, the required level of energy efficiency measures (EM) that should be applied to an electrical installation with ratings from EM0 to EM4 in each of 13 categories. The design should also influence the operational activities of the electrical installation after the commissioning stage. Three further categories specify the required energy efficiency performance levels (EEPL) rated from EEPL0 to EEPL4.

Most legislative initiatives on energy efficiency relate to new buildings. However, IEC 60364-8-1 recognises that the replacement of existing building stock is relatively low at around 2 % to 5 % per annum and it states that it should be applied to existing as well as new building stock. Applying a standard retrospectively is always difficult, but the standard states "it is in the refurbishment of existing buildings that significant overall improvements in energy efficiency can be achieved."

Other topics addressed by IEC 60364-8-1 include:

- (a) supplies and loads, control inputs and outputs;
- (b) Barycentres;
- (c) load management;
- (d) load types; and
- (e) installation maintenance.

All topics are explained in full in the [Designer's Guide to Energy Efficient Electrical Installations](#).

Energy efficiency of low voltage electrical installations

One new area within international standards is the integration of requirements for energy efficiency into IEC 60364 (the international standard that the IET Wiring Regulations (BS 7671) are based on). In this article, Geoff Cronshaw takes a closer look at energy efficiency of low voltage electrical installations. For an introduction to IEC 60364, see Cameron Steel's article in this issue.

In order to make improvements we need to be able to measure the amount of electrical energy consumed and monitor and control energy effectively. Energy measurement is essential for energy management. As a result, the design of the electrical distribution system needs to be carried out in such a way that will allow the metering and control of the various electrical loads in an installation. Also, in order to have an energy efficient installation, losses in equipment need to be as low as possible.

An important point when designing a new installation is to determine the most energy efficient location of the transformers (if any) and switchboards in an installation in order to minimise the electrical losses within the electrical distribution system. The objective is to locate the transformer and switchboard at the electrical centre of the group of loads they are feeding. The Barycentre method given in IEC 60364 -8-1:2014 provides a way of defining the most energy efficient location of the transformers and switchboards. The methodology described in IEC 60364 -8-1:2014 allows the designer to make both 2D and 3D calculations for the design of an installation. The 2D calculation can be used for single-storey installations and the 3D calculation can be used for multi-storey installations.

The Barycentre method

In this article we will look at an example of the 2D calculation for a simple single-storey workshop installation and how this calculation can be used for determining the ideal location of the switchboard that feeds a number of loads. There are several issues that determine switchboard locations, such as construction and layout of the building, incoming DNO supplies etc. and it may not always be practicable to locate switchboards in their optimum location from an energy efficiency point of view.

Firstly, it is worthwhile explaining the relationship between kWh and kW.

kW is a measure of power, whilst kWh is a measure of energy.

Energy = power × time.

kWh = kW × h

The estimated annual consumption (EAC) in kWh is normally used in the calculation. If the estimation of the annual consumption is unknown, the power consumption of the load can be used instead (according to IEC 60364 -8-1:2014) but this will give slightly different results.

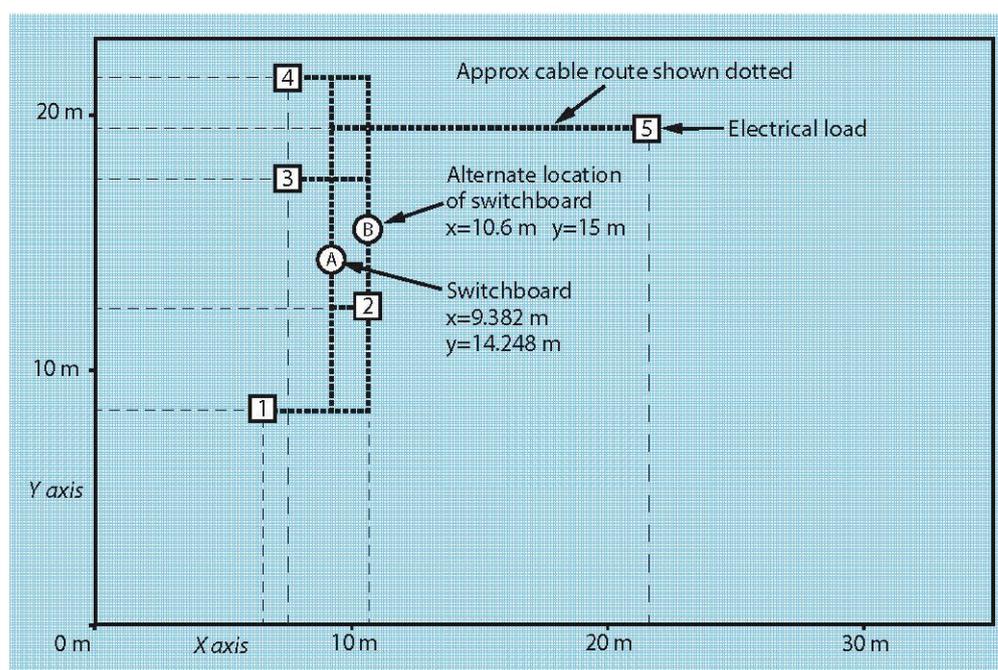
The Barycentre method equation for 2D layouts is as follows:

$$(X_b, Y_b) = \frac{\sum_{i=1}^{i=n} (X_i, Y_i) EAC_i}{\sum_{i=1}^{i=n} EAC_i}$$

If we take an example of a workshop with 5 loads as follows:

Table of peak demands (in kW) and x and y coordinates (in metres) showing locations of electrical loads			
Reference	Load in kW	X Coordinate	Y Coordinate
1	10 kW	6.5 m	8.5 m
2	20 kW	10.5 m	12.5 m
3	15 kW	7.5 m	17.5 m
4	5 kW	7.5 m	21.5 m
5	10 kW	21.5 m	19.5 m

Figure 1 Plan view of workshop



The EAC in kWh for the above loads, which are used at different times, is therefore determined as follows:

$$\text{kWh} = \text{kW} \times \text{h}$$

Table of the EAC of electrical loads in kWh	
Load reference	EAC
1	10 kW × 7h × 5 days × 45 weeks = 15,750 kWh per year
2	20 kW × 5h × 3 days × 45 weeks = 13,500 kWh per year
3	15 kW × 4h × 4 days × 45 weeks = 10,800 kWh per year
4	5 kW × 7h × 5 days × 45 weeks = 7,875 kWh per year
5	10 kW × 4h × 3 days × 45 weeks = 5,400 kWh per year

Table of EAC of electrical loads (in kWh) and the x and y coordinates (in metres) of the locations of the electrical loads.

Reference	Load in kWh	X Coordinate	Y Coordinate
1	15,750 kWh	6.5 m	8.5 m
2	13,500 kWh	10.5 m	12.5 m
3	10,800 kWh	7.5 m	17.50 m
4	7,875 kWh	7.5 m	21.5 m
5	5,400 kWh	21.5 m	19.5 m

According to the Barycentre formula:

$$(X_b, Y_b) = \frac{\sum_{i=1}^n (X_i, Y_i) EAC_i}{\sum_{i=1}^n EAC_i}$$

The X_b position of the Barycentre (for the switchboard location) is given by:

$$\begin{aligned}
 X_b &= \frac{(6.5m \times 15,750kWh) + (10.5m \times 13,500kWh) + (7.5m \times 10,800kWh) + (7.5m \times 7,875kWh) + (21.5m \times 5,400kWh)}{15,750kWh + 13,500kWh + 10,800kWh + 7,875kWh + 5,400kWh} \\
 &= \frac{500287.5}{53325} \\
 &= \mathbf{9.382 \text{ m}}
 \end{aligned}$$

The Y_b position of the barycentre (for the switchboard location) is given by:

$$\begin{aligned}
 Y_b &= \frac{(8.5m \times 15750kWh) + (12.5m \times 13500kWh) + (17.5m \times 10800kWh) + (21.5 \times 7575kWh) + (19.5 \times 5400kWh)}{15750 + 13500 + 10800 + 7875 + 5400} \\
 &= \frac{759787.5}{53325} \\
 &= \mathbf{14.248 \text{ m}}
 \end{aligned}$$

The location of the switchboard (item A) and the loads (items 1 to 5) and cable routes have been plotted in their approximate locations on the plan layout of the workshop (Figure 1). The estimated lengths of cables (in this example) from the switchboard to loads are given below. Please note these are only very approximate lengths. It is important to be aware that in practice it may not be possible to run cables via the optimum route due the building construction.

Load 1= 9 m, load 2= 3.5 m, load 3 = 5 m, load 4 = 9 m, and load 5 = 17 m.

Just as a comparison, if we use the power consumption of the load rather than the EAC in kWh, and in this example we use kW, we get:

The X_b position of the Barycentre is given by:

$$X_b = \frac{(6.5m \times 10kW) + (10.5m \times 20kW) + (7.5m \times 15kW) + (7.5m \times 5kW) + (21.5m \times 10kW)}{10kW + 20kW + 15kW + 5kW + 10kW}$$

$$= \frac{640}{60}$$

$$= \mathbf{10.6 \text{ m}}$$

The Y_b position of the Barycentre is given by:

$$Y_b = \frac{(8.5m \times 10kW) + (12.5m \times 20kW) + (17.5m \times 15kW) + (21.5 \times 5kW) + (19.5 \times 10kW)}{10kW + 20kW + 15kW + 5kW + 10kW}$$

$$= \frac{900}{60}$$

$$= \mathbf{15 \text{ m}}$$

The location of the switchboard (item B) and the loads (items 1 to 5) and cable routes have been plotted in their approximate locations on the plan layout of the workshop (Figure 1). The estimated lengths of cables (in this example) from the switchboard to loads are given below. Please note these are only very approximate lengths. It is important to be aware that in practice it may not be possible to run cables via the optimum route due to the building construction.

Load 1= 11 m, load 2= 2.5 m, load 3 = 5.5 m, load 4 =9.5 m, and load 5 = 15.5 m.

In this particular example using the load in kW compared to the using estimated annual consumption in kWh gives slightly different cable lengths. The difference could be far greater in other situations depending on the annual hours of use of the various loads.

Measurement and control

Figure 2 Photo of panel mounting and DIN rail mounting kWh meters with pulsed output



The electricity supplier only provides the metering that is required to obtain the basic data to enable tariff charges to be applied. While this may be adequate for the smaller installation, it does not give sufficient information to allow a larger energy consumer to allocate costs to various facilities or to control consumption.

To be able to measure the amount of electrical energy consumed and to monitor and control energy effectively, metering equipment needs to be allowed for at the planning stage. Although this will increase the initial cost of the switchboards, it will prove more economical than having to add metering equipment at a later date.

How metering information will be used needs careful consideration. The system may be required to measure power quality, voltage levels and loads. It may also produce alarms, control loads or change tariffs if preset limits are exceeded.

Consideration should be given to the environment in which the metering is installed, which should be in accordance with the manufacturer's instructions. Metering needs to be installed in an area that is accessible for the meter reader where the display can easily be read. Areas where the instruments are likely to be subjected to excessive heat, moisture, and vibration should be avoided. Meters are available that provide pulse generation. These can be linked to building management systems to provide an electrical pulse proportional to a unit of measurement.

Essential to the operation of the meter is the current transformer (CT). The function of the CT is to transform the high current levels to match the input requirements of the meter. In most cases the input value of the meter is 5 A. For example, the rating plate of a CT may show 400/5. The high value represents the maximum current of the circuit and is referred to as the primary value. The low value is referred to as the secondary value.

The accuracy is expressed as a percentage i.e. class 1 is 1 percent, class .5 is 0.5 percent.

Losses in transformers



Oil-filled substation transformer

IEC 60364-8-1 advises that the choice of an energy efficient transformer may have a significant impact on the energy efficiency of the whole installation. There are basically two types of losses in transformers. These are iron losses and copper losses. Iron losses occur in the magnetic core of the transformer, causing it to heat up. Iron losses can be divided into two components: hysteresis losses, and eddy current losses. In general it is understood that iron losses of a transformer remain constant regardless of load conditions, which means that the iron loss on no load will be the same as the iron loss on full load.

Copper losses (load losses) are due to the heating effect of the primary and secondary currents passing through their respective windings.

No-load and load losses in a transformer result in a loss of efficiency. They are the reason for the major running cost of a transformer. They result in heat that is normally dissipated to the atmosphere. Load losses depend on the load factor (LF). Consequently, a key requirement when considering energy efficiency is to decide on the load factor of the transformer at the planning stage in order to run the transformer at its most efficient.

IEC 60364-8-1 advises that the maximum efficiency of a transformer is when the iron losses and copper losses are equal. The standard advises that usually, the maximum efficiency of a transformer corresponds to 25 % to 50 % of maximum power rating of the transformer. Persons involved in this work should seek expert advice.

Current-using equipment

Current-using equipment efficiency is based on control of the loads (the right energy at the right time).

Motor control

Electric motors represent a large proportion of the industrial electricity consumption in the UK. Electric motors are used in a wide variety of applications in commercial and industrial installations. These include motors driving fans for ventilation and air-conditioning systems, motors driving pumps for refrigeration and chilling applications and air compressors.

Pumps and fans probably represent one of the largest applications for motor-driven power. The use of variable-speed drives (VSD) to adjust the speed of the pump or fan to deliver the required flow, could result in energy savings.

Lighting



Lighting controls

Lighting can represent a large percentage of energy consumption in buildings depending on the application. Solutions for lighting control could achieve significant savings on the electricity compared with a traditional installation (without automatic lighting controls). These systems should be flexible and designed for the comfort of the users. The solutions can range from very small and local controls, such as occupancy sensors, up to sophisticated customised and centralised solutions that are part of complete building automation systems.

Lighting controls

Lighting controls for residential buildings are easy-to-install devices that are able to detect the presence of people and only switch on lights when required. Lighting controls eliminate wasted energy and save energy simply by switching lights off when not required. Lighting controls for commercial, public and industrial buildings are again easy-to-install devices that are able to automatically switch off lights when no occupants are detected or there are suitable levels of natural light.

When considering the design and installation of lighting controls there are a number of important points to consider. First, it is important to take into account the type of space, how it is used and the amount of daylight available. The type and use of space will determine the type of sensor and therefore the control used.

Safety is also an important consideration. The operation of lighting controls should not endanger the occupants of the building. This may happen if a sensor switches off all the lighting in a space without daylight. It is therefore important that lighting controls are designed correctly to ensure the safety of occupants and save energy.

Commissioning should be included as an essential part of the installation of lighting controls. Commissioning could include calibrating photoelectric controls, checking that occupancy sensors are working, and setting a suitable delay time for occupancy sensors.

Power-factor correction

A poor power-factor (due to inductive reactance) is undesirable for a number of reasons. Power-factor correction technology is used mainly on commercial and industrial installations to restore the power-factor to as close to unity as is economically viable. Low power-factors are caused by reactive power demand of inductive loads, such as induction motors and fluorescent lights. A poor power-factor reduces the effective capacity of the electrical supply, since the more reactive power that is carried the less useful power can be carried. It also causes losses at transformers, can cause excessive voltage drops in the supply network and may reduce the life expectancy of electrical equipment.

For this reason electricity tariffs encourage the user to maintain a high power-factor (nearly unity) in their electrical installation by penalising a low power-factor. There are a number of ways in which power-factor correction can be provided. The most common way that this can be achieved is by the installation of power-factor correction capacitors. These can be installed in bulk at the supply position or at the point of usage on motors, for example. Persons involved in this type of work are recommended to seek advice from specialists on the most economic system for a given installation.

Harmonics

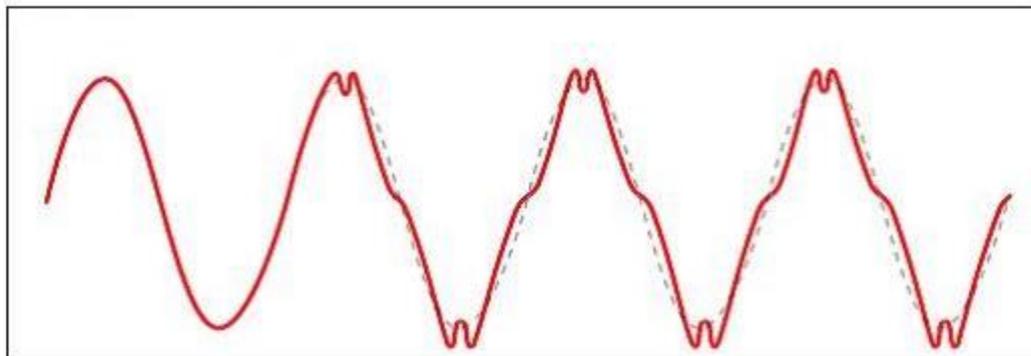
Harmonics are a steady-state disturbance compared with, for example, short-term transient overvoltages. Harmonics are generally caused by non-linear loads, such as switched mode power supplies of computers and discharge lighting (see Figure 3). Regulations 523.6.1 and 523.6.3 of the 17th Edition recognise the effect of triple harmonic currents in the neutral conductor and the need to take account of it. In electrical installations there is a particular problem in three phase circuits.

The third and other triple harmonics combine in the neutral to give a neutral current that has a magnitude equal to the sum of the third harmonic content of each phase. The heating effect of

this neutral current could raise the temperature of the cable above its rated value and damage the cable.

Other harmonics can cause problems with electric motors, causing the frame temperature to rise and, consequently, reducing the life and efficiency of the motors. With the increased use of switched mode power supplies the resulting harmonic distortion is a major concern. It is therefore important to be able to measure the power quality and, where harmonic distortion is found, provide a solution to reduce the harmonic distortion.

Figure 3 Harmonics



Renewable energy



A wind generator. Thanks to Dr Sung for the photo.

On-site renewable energy sources do not of themselves increase the efficiency of the electrical installation but reduce the overall utility network losses as the consumption of the building from the utility is reduced.

There are a wide range of microgeneration technologies, including solar photovoltaic (PV), wind turbines, small-scale hydro, and micro CHP (combined heat and power).

Microgeneration systems such as solar PV installations should always be carried out by a trained and experienced installer. For example, where the PV panels are roof-mounted the roof must be strong enough to take their weight, especially if the panel is placed on top of existing tiles. It is also important to note that there are mandatory requirements concerning the parallel connection of generators with the supply network.

Conclusion

IEC 60364 -8-1:2014 is a completely new Standard. The worldwide need to reduce the consumption of energy means that we have to consider how electrical installations can provide the required level of service and safety for the lowest electrical consumption. The Standard enables a client to specify the level of energy efficiency measures applied to an electrical installation. Energy efficiency ratings are included for a wide variety of equipment types and installations, including motors, lighting, HVAC, transformers, wiring systems, power-factor correction, measurement, and renewable energy. Also, information on sizing cables to reduce energy losses in conductors is included. This article is only intended as a brief overview of energy efficiency.

Further information

For further information refer to:

- [Designers Guide to Energy Efficient Electrical Installations](#) by the IET
- IEC 60364 -8-1:2014, BS 7671:2008+A3:2015
- Engineering Recommendations G83/1 and G59/1 published by the Energy Networks Association and the Department for Business, Enterprise & Regulatory Reform (BERR).

For England and Wales - The Department of Communities and Local Government
www.communities.gov.uk

For Scotland - [The Scottish Building Standards Agency](#)

Note: there are many sources of further information. The ones listed above are just a few. It is important to consult the Building Regulations in the UK when designing electrical installations. The Building Regulations contain requirements for lighting controls etc.

Connected systems: interview with Sam Woodward

Sam Woodward is author of the Code of Practice for Connected Systems Integration in Buildings. He is also Lutron's Customer Education Leader for Europe and Africa, managing Lutron's Lighting Control Institute in Europe. We catch up with Sam about what 'connected systems' means, what customers are asking for, and what electricians and installers need to know.

Sam, what exactly is a 'connected system'?

A 'connected system' is one in which a number of devices communicate together in order to facilitate system features that any one product on its own would not be able to achieve. Connected systems offer building users more convenience, more comfort, a better sense of security, and even access to services when not in the building. Networks of devices designed as a system enable greater automation due to convergence of systems. For example, controlling your lighting, shading and temperature together or using one button to do a whole-building-off command that controls both lights and AV together.

Tell us about your experience. Have you worked in the area of connected systems long?

Yes, I've worked with a variety of connected systems. For a decade I focused on product development, designing dimming systems and software. I now teach lighting controls to electricians, installers, programmers, architects and specifiers, looking after customer education for Lutron in the Europe and Africa regions. However, I started my career in the entertainment industry, developing electronic control systems for film, TV and theatrical effects, primarily integrating lighting/laser and video systems with live pyrotechnics. The world of building automation may be a far cry from creating fireballs in a stadium for a pop concert [credits include special effects for James Bond, Lara Croft, and Robbie Williams], but many of the electrical principals behind safe and reliable connected systems are the same!

What drew you to this area of the industry?

This is a very exciting industry to be working in, with interesting projects, a wide variety of clients, and an ever-changing pallet of technologies. The IoT (Internet of Things – also known as M2M or Machine to Machine communication) brings many opportunities that enable technology to increase our standard of living or to enhance our working environment. We all have an imperative to conserve energy and to make buildings 'greener'. It's easier than you may think to conserve energy with modern reliable occupancy sensors, and integration with heating and lighting systems. I personally find that working with many different systems and learning from experts in different fields of technology, but at the same time building a unified whole system, to be endlessly fascinating.

How has the market grown, and what trends have led that development?

We are at an exciting time in the building automation industry right now with three simultaneous revolutions occurring. Firstly there is a tremendous renaissance in the design of good user interfaces for systems, both in terms of smart-devices and voice-control, but also with keypads and touchscreens that look less 'geek' and are easy to use by everyone. Controls need to be simple and accessible for all building users to operate, and should be clear in their operation; we are starting to see some great products that enable just that. At the same time there's a rapid rise in networking technologies; both wired and wireless, enabling devices and users to connect, often from anywhere in the world. Simultaneously the

lighting industry, which provides major elements of the connected building, is seeing a revolution in light-sources as LED replaces more traditional types of lamp and fixture. This not only contributes to energy saving, but also opens up exciting new artistic and aesthetic possibilities.

What trends are emerging now?

We are seeing a rise in the use of wireless systems for automation. This isn't new technology, as patents on wireless control systems date back decades now, but the increasing popularity of smart devices and networked systems are leading to a huge growth in adoption of wireless systems. As explained in *Code of Practice for Connected Systems Integration in Buildings*, this can enable systems to integrate in new ways, but installers do also need to be very cautious about the parts of the radio spectrum used, as the radio-waves are a very finite resource, and so do not assume that wireless networks can always be a direct or fully reliable substitute for wired systems.

At one point smart homes seemed to be the stuff of aspirational décor magazines or complicated technical discussions – are you seeing prices coming down and more mainstream demand for smarter homes?

Yes, very much so. Technology for energy-saving, or devices that increase our convenience, and systems that deliver new types of entertainment to our homes are mainstream now. Installers need to be cautious about compatibility issues between different systems, but it is certainly the case that useful systems can be installed for hundreds, rather than thousands, of pounds.

How successful can a retrofit be? Or do you need to start with a completely clean slate in order to have a really successful connected system for the home?

Retrofit systems can be very successful. Wireless products offer opportunities for installation where adding new cables may not be possible, but there can be risks in relying on entirely wireless systems. Installers should be careful of over-optimistic 'best case' indications of wireless range from manufacturers: instead ensure that you ask for real-world, indoor, guaranteed distances. Remember especially that the 2.4 GHz part of the spectrum is extremely congested in urban environments, and so alternatives should be considered.

There are a lot of various platforms, such as Apple HomeKit. Do you need to make your platform decision early on and stick to it, or is there a degree of flexibility?

As the IoT world is really still in its infancy there is not yet a dominant protocol, and so compatibility issues are a major challenge at the moment. There are many devices which 'speak' multiple different machine-to-machine languages, translating between different APIs (application programming interfaces), but often specialist programming skills are required to 'glue' them together. In designing a system always start with a detailed discussion on the specification of the automation behaviour required in a building. It is likely in the long-term that we will see buildings that are dominated by one particular set of protocols over another, but at the present time the sheer variety of electronic systems available will ensure that the 'Tower of Babel' remains with us for some time to come.

How can Wiring Matters readers get involved with working with smart homes and connected systems?

Start by having a conversation with your customers about how they use their buildings and to consider how connected systems can bring convenience, energy-conservation and can also act as a useful way of complying with legislation such as Part L of the Building Regulations. There are various organisations, such as the IET and CEDIA, who have a lot of educational material in this area, and manufacturers have extensive education programmes to encourage and assist electricians who want to add more value to their jobs with this new technology.

Remember that the basic physical principals of system design are the same across all products, and so good preparation and planning of an installation will lead to a more successful project. The IET's *Code of Practice for Connected Systems in Buildings* gives extensive guidelines to engineer reliability into system designs.

Now is a great time to start adding more value to your projects by including and interconnecting this exciting technology.

Are you working on jobs that involve home automation, smart installations or the connected home? The IET's *Code of Practice for Connected Systems Integration in Buildings* is available to [buy now](#) for £60 (£51 for IET members).

In the Winter issue of Wiring Matters (due to be published in November) we will include more articles about the smart home. If there's anything specific you would like to learn about, please email us: wiringmatters@theiet.org

Reduced low voltage

Mark Coles examines the wiring requirements for a reduced low voltage circuit.

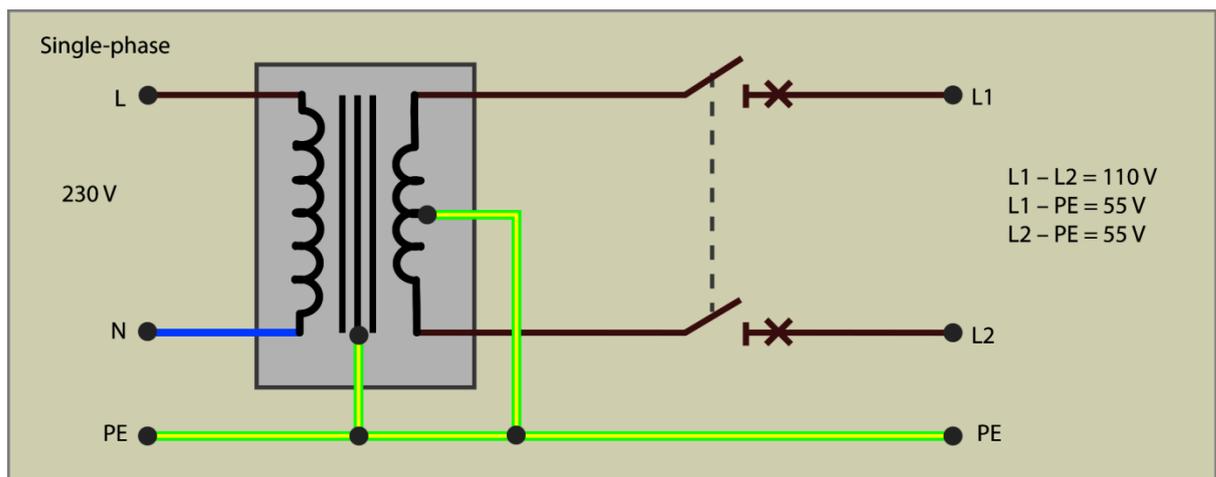


What is reduced low voltage?

Regulation 411.8.1.2 of BS 7671:2008+A3:2015 defines the nominal voltage of a reduced low voltage system as:

... not exceeding 110 V a.c. rms between lines, i.e. three-phase 63.5 V to earthed neutral, single-phase 55 V to earthed midpoint.

The below figure clarifies this:



Single-phase reduced low voltage system

Point 'PE' is earthed midpoint. The transformer is also known as 'centre-tapped'.

Where does a reduced low voltage system fit alongside other systems in BS 7671?

BS 7671:3008+A3:2015 generally recognises four protective measures against electric shock in Regulation 410.3.3:

- automatic disconnection of supply (Section 411);
- double or reinforced insulation (Section 412);
- electrical separation (Section 413); and
- extra-low voltage (SELV and PELV) (Section 414).

In areas of increased risk, it is common to see a reduced low voltage system in use. In a reduced low voltage system:

- basic protection is provided by basic insulation or barriers and enclosures; and
- fault protection is provided by automatic disconnection of supply with an overcurrent protective device in each line conductor.

A reduced low voltage system is recognised as a safe way of providing an electrical supply for equipment in more onerous environments or areas of increased risk. Areas include construction sites and workshops, and laboratory supplies for such items as:

- portable and hand-held tools;
- site lighting (other than fixed flood lighting); and
- portable hand-lamps (general use).

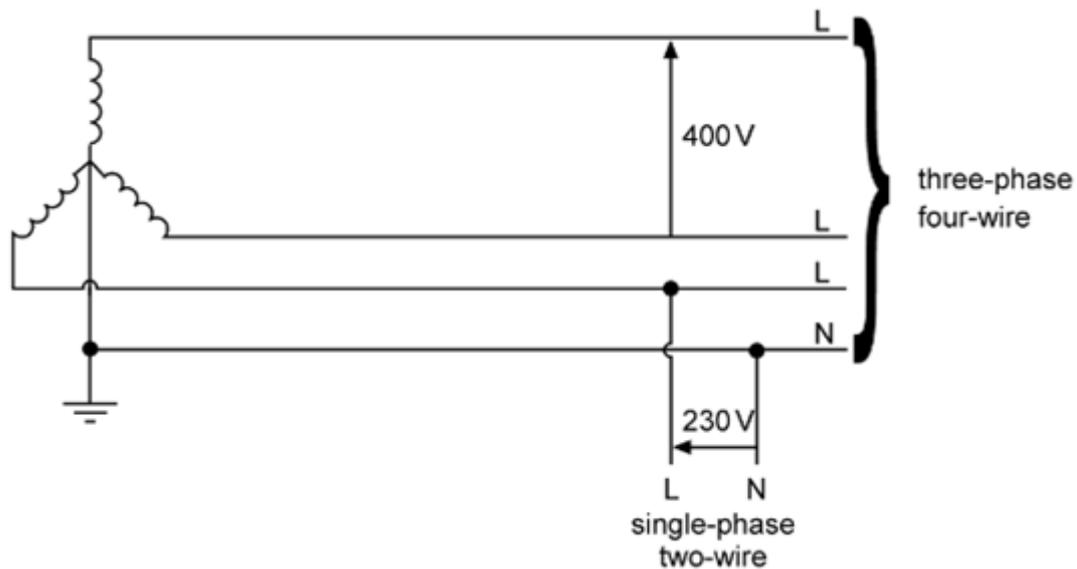
The system has its origins in the 1949 Annual Report of HM Chief Inspector of Factories, which recommended the system for use on building and construction sites and other applications involving large-scale use of portable electric tools. The system was described in the British Standard Code of Practice, CP 1017:1969, *Distribution of Electricity on Construction and Building Sites* (superseded by BS 7375:1991, now BS 7375:2010). Equipment was specified in BS 4363:1969 *Specification for Distribution Assemblies for Electricity Supplies for Construction and Building Sites* (now BS 4363:1998+A1:2013, also BS EN 61439-4:2013).

The intention of a reduced low voltage supply is that should a person come into contact with a line conductor, the maximum voltage they would be exposed to is 55 V.

55 V can still be dangerous if tools and equipment are not used correctly and maintained, but no deaths have ever been recorded where a person has been exposed to a 55 V electric shock.

Conductors

Note that a single-phase reduced low voltage supply does not have a neutral conductor. Consider a 230 V AC single-phase supply where one pole of the supply is earthed; this is usually at the transformer on a TN or TT system. The below figure shows the conventional UK supply system.



UK supply system

This connection creates a conductor we reference as neutral. On a reduced low voltage system there is no neutral; the centre point of the transformer's secondary winding is earthed, so, each leg of the circuit emerging from the transformer is at equal potential to each other with respect to earth.

Conductor identification

Regulation 514.3.1 states that conductors shall be identified by colour or by an alphanumeric method. Further, Table 51 of BS 7671:2008+A3:2015, *Identification of conductors*, sets out the standard method; extract here:

TABLE 51 – Identification of conductors

Function	Alphanumeric	Colour
Protective conductors		Green-and-yellow
a.c. power circuit		
Line of single-phase circuit	L	Brown
Neutral of single- or three-phase circuit	N	Blue
Line 1 of three-phase a.c. circuit	L1	Brown
Line 2 of three-phase a.c. circuit	L2	Black
Line 3 of three-phase a.c. circuit	L3	Grey

Where colour is used to identify the conductor, the line conductor of a single-phase circuit is identified with brown; neutral is identified with blue. However, there is no neutral conductor in a single-phase reduced low voltage 55-0-55 V system; therefore, no neutral means no blue conductor. As both live conductors of the circuit are at exactly the same potential with respect to earth, i.e. 55 V AC, they would, therefore, need to be the same colour. Remember, these conductors are not of different phases, there is no angular displacement between them, they are two poles of the same phase; therefore brown is used for each conductor.

Is there a concern about polarity?

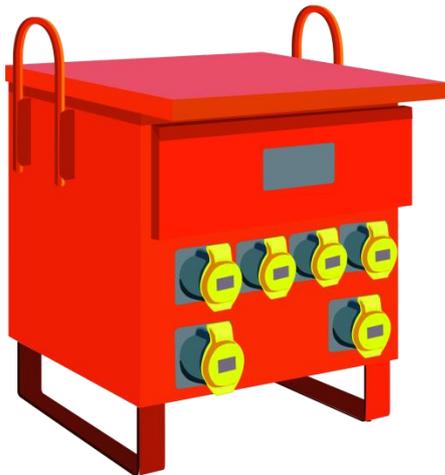
As each conductor is from a circuit of alternating current, and each conductor is at the same potential with respect to earth, there is no discernible advantage in maintaining polarity.

Identification at the socket-outlet

The very slight fly in the ointment here is the identification of terminations at 110 V socket-outlets for use in AC systems. BS 4363:1998+A1:2013 states in clause 11 *Terminal markings and identification of connections* that:

... the neutral conductor terminal shall be identified N.

In a 55-0-55 V reduced low voltage system there is no neutral conductor, but bear in mind that not every 110 V system is center-tapped. Equipment can be used/operated at 110 V to earth where transformers are not centre-tapped but have one pole earthed to create a neutral conductor. Consequently, manufacturers mark terminals as 'L' and 'N' to allow for systems that require polarity to be maintained.



Typical 110 V (55-0-55) power assembly

Summary

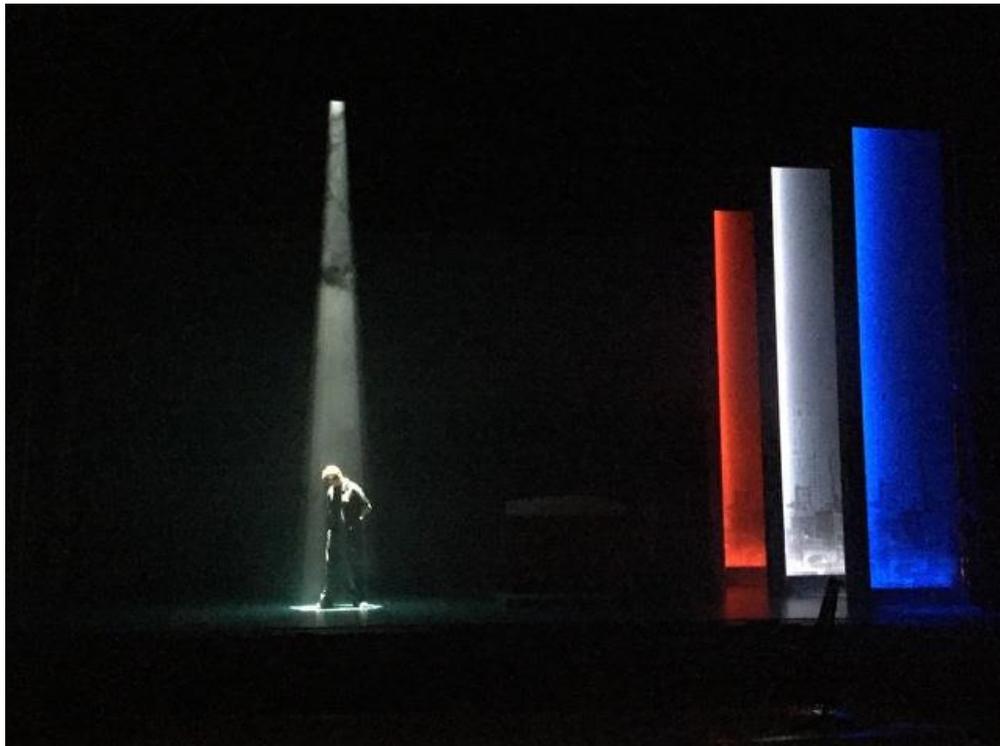
Reduced low voltage systems are used extensively in construction sites, workshops and for supplies to laboratory equipment. Socket-outlets on a single-phase reduced low voltage circuit will have three conductors; the protective conductor will be identified by green-and-yellow markings whilst the two current-carrying conductors, also known as live conductors, will both be coloured brown where colour is used as the identifying medium. There is no requirement to maintain polarity between the live conductors.

Further reading

- BS 7671:2008+A3:2015 *Requirements for Electrical Installations*. IET Wiring Regulations 17th Edition 411.8 Reduced low voltage systems
- IET *Commentary on IEE Wiring Regulations 17th Edition* Chapter 4, clause 4.4.10.1
- IET *Guidance Note 7 Special Locations* Chapter 4 *Construction and demolition site installations*
- BS 4363:1998+A1:2013 *Distribution assemblies for reduced low voltage electricity supplies for construction and building sites*

Backstage at the theatre: what it takes to power a show

Ever wondered what's involved in producing a theatre show? In this issue ABTT member James Eade gives readers a peep into backstage life and talks to some fellow members about their current projects and what the job of a production electrician entails.



Focussing. Once the system is installed, lights are positioned, focussed and programmed in preparation for being used during the show.

Theatre shows are incredibly varied in their scale and complexity, from the simplest amateur dramatics and school plays right through to big-budget West End performances. Common amongst nearly all of them is the use of power, particularly for lighting but also for sound, stage automation, video, effects and so on. Typically a production electrician will be responsible for designing and creating power systems for these as well as providing data control networks for the lighting. Production electricians are often also involved in the design of bespoke effects for performances such as flying cars (*Chitty Chitty Bang Bang*), flying elevators (*Charlie and the Chocolate Factory*) or magic wands (*Harry Potter and the Cursed Child*). These can be challenging as they have to be powered discretely and operated in a manner that appears imperceptible to the audience – it is the magic of theatre, after all....!

There is no such thing as a typical day for those involved in such projects, so what is it like to work on such shows? And how would one get started in technical theatre? We thought we'd ask four individuals responsible for many of the high profile shows that have been staged in the West End in recent years to give us their views: Nick Mumford, Martin Chisnall, Pete Lambert and Robin Barton.

Current projects

To give the reader an idea of the breadth of projects undertaken, we asked what current jobs they are working on. It should be borne in mind that some shows do have confidentiality agreements while they're in the making, so the descriptions may not be complete!

For Robin, the bulk of his current workload is manufacturing bespoke lighting systems:

"We're developing some custom control gear and LED fixtures for the National Theatre, working on an amazing new piece for Lucy Carter, a starry night sky for a whole auditorium, and a show set in a recording studio."

Far from most peoples' minds at this time of year is Panto season. But for Nick, work has already started on the planning of four of them at opposite ends of the country: Newcastle Theatre Royal, Edinburgh Kings Theatre, the London Palladium and the Birmingham Hippodrome. And that's not all:

"I'm currently the production LX ['LX' is theatre-jargon for *electrics* or *electrician*] for *Breakfast At Tiffany's*, currently playing in the West End then touring the UK, as well as being the Technical Production Manager for the UK tour of the Alvin Ailey American Dance Theater, starting at Sadler's Wells in September."

Martin has just completed a job that many would be deeply envious of:

"I've just finished *Harry Potter and the Cursed Child* at London's Palace Theatre where I was working as senior production electrician. Future projects include *The Entertainer*, the last show in the Kenneth Branagh Season at The Garrick Theatre; *Lazarus*, the new musical by David Bowie in a tent at King's Cross and The Commitments UK tour."

On top of all of that, Martin also looks after the *Mamma Mia!* touring productions both in the UK and internationally.

Pete is getting his passport up to date:

"I've just finished setting up the next *Wicked* tour, which is currently in Bradford, next stop Singapore. The next two years are touring in the Far East, then slowly heading back to the UK via a couple of European venues. It's my third *Wicked* project having set it up in London 10 years ago. Also, I'm working on *School of Rock* at the New London Theatre. We're just in the bidding stage and as usual there's not enough cash to pay for the kit the designer wants! I hope they sort it out soon, we're scheduled to load in in just over a month's time...."



Lighting being rigged and cabled onto a theatre's fly bar at stage level, before it is flown out to a show height of around eight or nine metres.

Variety is the spice of life...

As you can see, the work is varied and a lot of travel is often involved. But for many in the industry, theatre shows alone do not come around frequently enough to pay the bills and so work in allied areas is common. Martin's background though has always been theatre:

"When I first went freelance I did a much wider variety of work; events, corporate, exhibitions, even a little bit of TV as well. But now I do almost exclusively theatre, although increasingly I now also teach and carry out consultancy work."

Robin's work is also mostly theatre based, although he also does some infrastructure and systems work, such as installing new lighting control networks, for example. But for him "the corporate and events market is an important sector for us too, it is not just 'filling in' between other shows."

Pete spends "a good 80 % of my time purely on theatre shows, but I go off and do a bit of corporate work mostly for a company based in Woking."

Recent years have seen Nick more and more focussed on theatre shows although "I do still occasionally get involved in a wide variety of other events. These range from conferences and other corporate events to fashion shows, site-specific productions, television work, parties, ice-rinks, sports events and so on."



Almost theatre, but not quite – backstage lighting dimming, distribution and control for the BBC EU Referendum debates in Wembley Arena.

So what do you actually do?

Nick and Martin concur on the description of the role of a production electrician as being someone who:

“Takes a designer's lighting plan and assembles all the component parts to deliver a fully functioning lighting system with which they can light the production. That involves liaising with the designers (lighting, and sometimes set designers), the lighting company that might be providing any hired equipment, the electricians in the venue (or venues), along with the Production Manager and the crew chiefs of other departments who might need power or other integration.”

Martin points out that it involves “a lot of lists: lighting equipment lists, colour lists, gobo lists, moving light configuration lists, cable lists, rigging lists, DMX [data control] addressing lists, budgets, crewing lists etc ...”

Once all the equipment is specified (and approved on budget!), the next stage is to spend some pre-production time building the rig into a kit-form to ensure quick assembly when on site. Nick goes on to explain that:

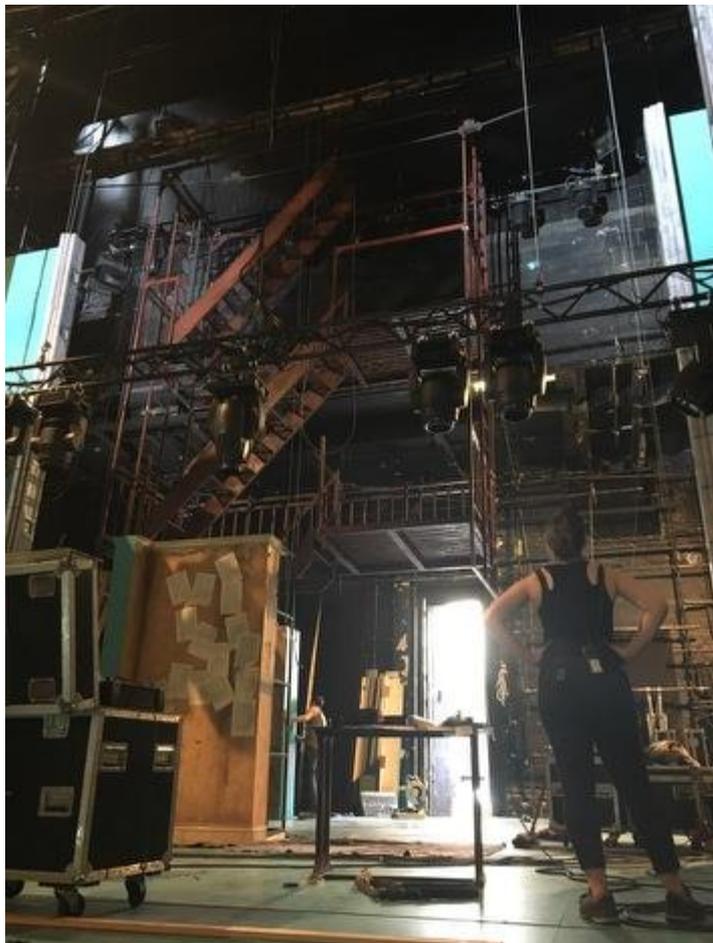
“The role then involves installing the system in the venue. That means working with the venue's local crew and guiding them through piecing together the kit that you have prepared in advance. Once everything is installed, functioning and the lights have been focussed to perform their intended tasks, the role becomes one of tech support to keep the increasingly complex equipment that is used functioning throughout the show's creation process.”

This process is then reversed if the show is touring and it gets packed back up and loaded onto the trucks to go to the next venue to be re-created. This happens multiple times on tour in different locations, often under fairly intense time constraints.

Robin highlighted the close liaison with the creative minds involved in a show:

“Sometimes we are involved from the conception, other times *slightly* later, but we are always there until the end. A large part of our role is to interface between the creative and engineering disciplines. From my perspective we specialise in delivering unusual projects – from miniature ‘invisible’ items to larger projects such as flying 100 kg of lighting equipment across a stage in a 24 m by 9 m arc.”

Martin agrees that “the designer and I must work closely as a team and occasionally my advice or opinion may be sought. Sometimes I can’t help myself and offer my opinion anyway! Sometimes a designer may have an idea but not know the best way to achieve it in practice, or know if it is even possible. I may be asked if I know of a fixture that has a particular set of features, or produce a special effect.”



Different scenic and technical elements jostling for position halfway through a show build.

Nick notes that “whilst the lighting design is not your responsibility as the production electrician, an understanding of it is essential to be able to specify and manipulate the equipment in such a way as to make its delivery possible.”

Pete acknowledges that “as I get older there are an increasing number of youngsters picking up the baton. I really enjoy working for them and being paid ‘from the neck down’ – sometimes when you’re in charge you don’t get to do some of the basics, like actually using a light. That’s something I have always enjoyed.”

Electrical design work

The electrical considerations are not quite the same as ‘traditional’ electrical design as Martin explains:

“I work out how everything is going to be plugged up. Where is every piece of equipment going to get its power from? How long a piece of cable will it need? What size cable with what connector on the end? Does it need a dimmer or non-dimmed power? How many dimmers and MCBs in total will I need? How much total power will I be likely to need? Will I need to get more dimmers, or distribution equipment, or even more power? How many DMX slots does it require? Where will it get its data from? How will the lighting equipment be physically rigged? How will it be maintained?”

Nick neatly describes what they all agree on, and that is that the electrical planning and prep time is hugely important.

“Whilst it is a reasonably short period relative to the amount of time a production may be on the road or sat in a specific venue, how productive that period is really dictates how smooth your life will be for the foreseeable future.”

The electrical equipment used on theatre productions is very much of a ‘plug and play’ nature. This is to enable the quick assembly of systems and to be able to take them apart again quickly too. Often this needs to happen in a few hours overnight, possibly the day before putting it all together again a couple of hundred miles away.



Mains distribution equipment backstage. The rack on the left is a 108 x 10 Amp channels of single phase power distribution, in the centre is a 16 way three-phase distribution unit, the rack on the right is control data distribution.

The starting point of the electrical design is really concerned with the safe loading of these distribution systems when they are hooked up to the power supplies available in the theatres that the show is visiting, the electrical characteristics of which are often unknown. Nick explains:

“A sensible level of discrimination is necessary, both from a safety point of view (earth faults, isolation and switching etc.), but also from the point of view of user friendliness and ease of operation. Given that these systems are being repeatedly taken apart and put back together by different crews each week (albeit under the supervision of the production electrician), the system needs to be robust and clearly labelled to make sure it is assembled as per the specification each time.”

A certain amount of flexibility needs to be designed into that system too. You can be sure that, certainly in a show's early days, there will be changes to the lighting design. The creative team are not generally concerned about how many spare ways you have left on your distribution equipment or dimmers. Nor do they worry about how you are dealing with phase balancing during a show where the demand is constantly shifting as different lights are used in the different scenes being played out onstage. From a design point of view, they might suddenly require the biggest light they can find to be rigged in the most inaccessible position possible, where you previously had no power or data infrastructure in place.”

As well as the instruments lighting the stage, there may be electrical elements that form part of the production's scenery. At this point it can become part of the production electrician's role

to specify and install some of this, whether that is more lighting or other practical, electrical items. This can sometimes be more of a traditional 'install' type of job, where the electrics are more permanently fitted to remain part of the set as it travels. Often now it is a job for a separate electrician, or team of electricians, given the tendency for many bits of scenery or props to have to light up. Since the arrival of LEDs, this has become an area that can involve wiring jobs that are much more bespoke, involving a soldering iron rather than a plug and socket.

Martin noted that the job is also 'systems integration':

"Taking a load of random equipment from different manufacturers and making them all work together to produce a show. Increasingly I also need to be a computer network engineer as increasingly there are as many IP as there are DMX addresses to be configured."

But Pete sums up the process quite elegantly: "As an old friend and colleague, Dobin, used to say, "we turn the ideas and dreams of the designer into a working reality".

In the next issue of Wiring Matters, James speaks with Nick, Martin, Pete and Robin about their best and worst experiences, and advice they would give to those wanting to work in theatre.

Launch of Job Profile Bank on Student's Hub

Wiring Matters has recently launched a Job Profile Bank on the [Student's Hub](#). The Job Profile Bank will showcase the wide variety of job types available to electricians, and is made up of interviews with electricians and technicians from different areas of the industry.

We currently have interviews with domestic installers, an inspector, a business owner, a smart home installer and several technicians within the entertainment industry.

Get involved

We hope to create a wide collection of job profiles so that young electricians can be inspired to work in many different areas of the electrical industry.

Please let us know if there are any areas of the electrotechnical industry you would like to see in the Job Profile Bank and we'll do our best to get an interview with someone in that area.

Similarly, if you have an interesting role and you'd like us to interview you, please get in touch!

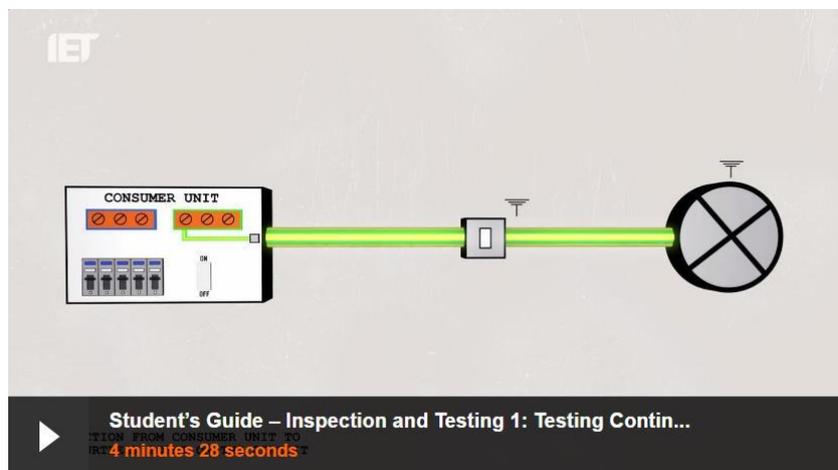
New videos published on the Student's Hub

Author of the Student's Guide to the IET Wiring Regulations *Steven Devine* presents two technical videos relating to testing and inspection.

Published May 2016

[Testing & Inspection 1: Testing Continuity of Circuit Protective Conductors \(CPC\)](#)

Testing the continuity of the circuit protective conductor (CPC) correctly is absolutely essential to confirm that your installation is safe, meets the requirements of the Wiring Regulations as well as to complete exams in accordance with the requirements of awarding bodies.



Published July 2016

[Testing & Inspection 2: Insulation Resistance](#)

Testing the insulation resistance of a circuit is another essential test that must be correctly carried out so that you can determine an installation is safe, meets the requirements of the IET Wiring Regulations and satisfies assessment requirements in accordance with awarding bodies.



About the Student's Hub

The [Student's Hub](#) showcases all material produced by the IET that might be of interest to those studying and working towards becoming an electrician.

The Hub includes videos and news relevant to students, as well as the brand-new Job Profile Bank to give young electricians and students an idea of what they can do with their qualifications.

About the *Student's Guide to the IET Wiring Regulations*

This highly illustrated guide is written with the student in mind. It takes the reader through each fundamental topic that will need to be understood when pursuing studies and entering the electrotechnical industry. Topics include generation and transmission, earthing and bonding, and fault finding.

The publication has been endorsed by the Plain English Campaign – meaning the text is clear and easy to understand.

About the author

Steven has a passion for providing students with a clearer understanding of the importance of standards and the Wiring Regulations. His background is in education, having lectured at Cambridge College. He also serves as Secretary to Panel C Shock Protection, one of the four panels that make up the decision-making committee behind the IET Wiring Regulations, JPEL/64.

Student Roadshows

We'll be rolling out Student Roadshows to colleges around the UK. As part of the Roadshow, we'll bring speakers, a knowledge competition with prizes, and freebies to your college. If you'd like to register your interest to host a Student's Roadshow, please contact us.

You can view our first Student Roadshow [here](#):

