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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.

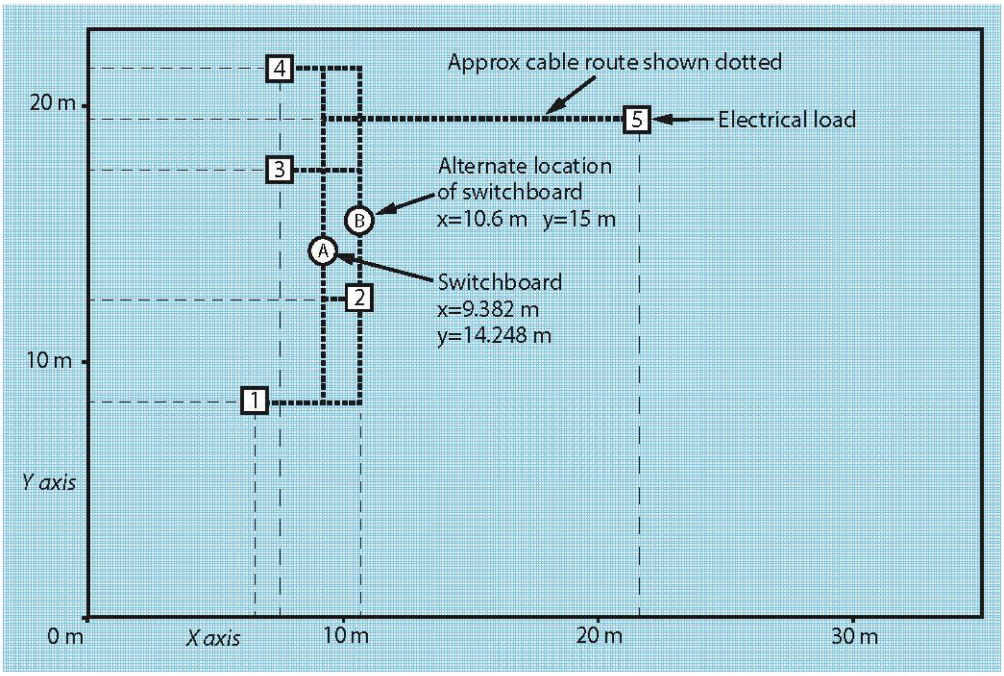
The Barycentre method equation for 2D layouts is as follows:

$$(\mathrm{X_{b,}Y_b}) = \frac{\sum_{i=1}^{i=n}(X_{i,}Y_i)\mathrm{EAC_i}}{\sum_{i=1}^{i=n}\mathrm{EAC_i}}$$

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:

kWh = kW × 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:

$$(\mathrm{X_{b,}Y_b}) = \frac{\sum_{i=1}^{i=n}(X_{i,}Y_i)\mathrm{EAC_i}}{\sum_{i=1}^{i=n}\mathrm{EAC_i}}$$

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

$$X_b = \frac{(6.5m\times15{,}750kWh)+(10.5m\times13{,}500kWh)+(7.5m\times10{,}800kWh)+(7.5m\times7{,}875kWh)+(21.5m\times5{,}400kWh)}{15{,}750kWh+13{,}500kWh+10{,}800kWh+7{,}875kWh+5{,}400kWh}$$

$= \frac{500287.5}{53325}$

= **<u>9.382 m</u>**

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

$$Y_b = \frac{(8.5m\times15750kWh)+(12.5m\times13500kWh)+(17.5m\times10800kWh)+(21.5\times7575kWh)+(19.5\times5400kWh)}{15750+13500+10800+7875+5400}$$

$= \frac{759787.5}{53325.}$

= **<u>14.248 m</u>**

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:

$$X_b = \frac{(6.5m\times10kW)+(10.5m\times20kW)+(7.5m\times15kW)+(7.5m\times5kW)+(21.5m\times10kW)}{10kW+20kW+15kW+5kW+10kW}$$

$= \frac{640}{60}$

= **10.6 m**

The Y_b position of the Barycentre is given by:

$$Y_b = \frac{(8.5m\times10kW)+(12.5m\times20kW)+(17.5m\times15kW)+(21.5\times5kW)+(19.5\times10kW)}{10kW+20kW+15kW+5kW+10kW}$$

$= \frac{900}{60}$

= **15 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 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.

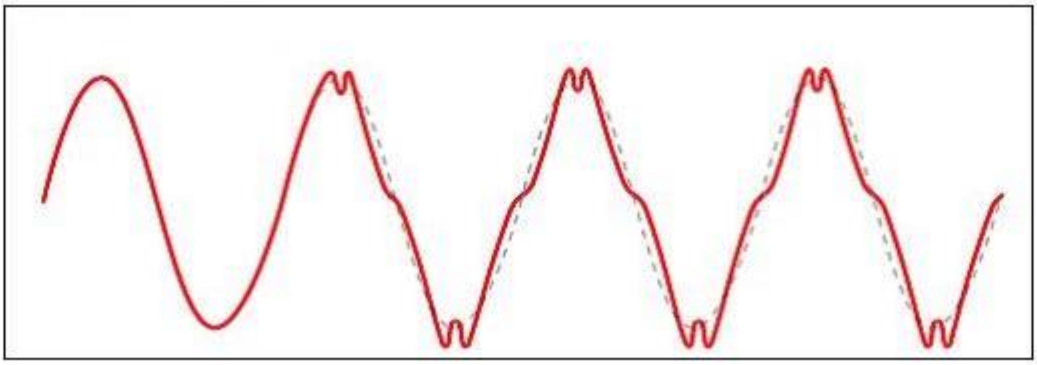
Harmonics

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.