Technology guide

CARBON TRUST

Making business sense of climate change

Voltage management

An introduction to technology and techniques

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Foreword

This document is designed to answer your questions on voltage management. It also explains how you can save both energy and money by making sure your electricity supply is set at an optimal level across your site.

It is aimed particularly at the operators of larger non-domestic premises, which typically have a three-phase electricity supply.

We introduce the concept of voltage 'dependent' and voltage 'independent' loads and establish a step-by-step procedure to help you estimate the energy and cost saving potential of voltage management.

Voltage management is just one of a number of energy management technologies. Before you commit to the costs involved, you should compare the benefits of installing voltage management equipment with those of alternative energy efficiency projects that remove voltage dependent loads and break the relationship between site energy demand and the supply voltage. You may also want to consider the impact the two types of project have on each other, as you'll need to decide on the best order in which to implement them.

Further information

If you're thinking about installing voltage management equipment, this guide can help you understand the opportunity and evaluate the possible savings. To weigh up the advantages of alternative projects, such as changing lighting equipment or installing variable speed drives, you may want to consult other Carbon Trust publications, such as CTV021 Lighting Technology Overview and CTG006 Variable Speed Drives Technology Guide

Understanding voltage management

What is voltage management?

Voltage management is an umbrella term covering various distinct technologies, including voltage optimisation, voltage stabilisation, voltage regulation, voltage power optimisation, or voltage reduction. In the context of this document, we've used the term to maintain an impartial position with regard to equipment selection.

If your site is being supplied with electricity at a higher voltage level than you need, you could be wasting energy and money, and be responsible for greater emissions than necessary. This is where voltage management can help.

Electrical equipment can sometimes consume more power at higher voltages. Voltage management reduces the voltage of the electricity supplied to equipment, minimising consumption while remaining within the operating conditions specified by the equipment manufacturer.

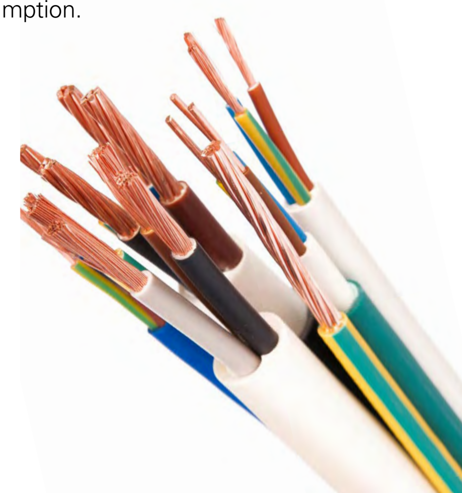
Basic electrical laws mean the power required by certain loads is proportional to the square of the voltage. A supply voltage in excess of the nominal 400/230V may result in excessive energy consumption.

How does it work?

The basic principal of all voltage management equipment is to reduce the voltage level from that of the incoming supply. To achieve this change in voltage level, an electrical transformer is required.

The ratio of primary to secondary windings of these electrical transformers is set to provide the desired level of voltage reduction.

Whilst there are a range of manufacturers and various specifications of voltage management equipment, it is this fundamental device which sits at the heart of the equipment.



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Why might my supply voltage be higher than necessary?

Until 1995, the statutory supply specification in the UK was 415/240V ±6% (i.e. phase voltage (Vp) within the range 226-254V). The vast majority of the electrical distribution network has been in place for many years and was designed to deliver electricity within this range. There are many sites across the UK where the phase voltage is normally in excess of 240V.

Historically the supply voltage in mainland Europe has been 380/220 volts with a typical tolerance of ±6%. Steps to harmonise voltage levels were taken in 1995 when the statutory supply specification in the UK changed to 400/230V+10% -6%. This remains the current UK position today.

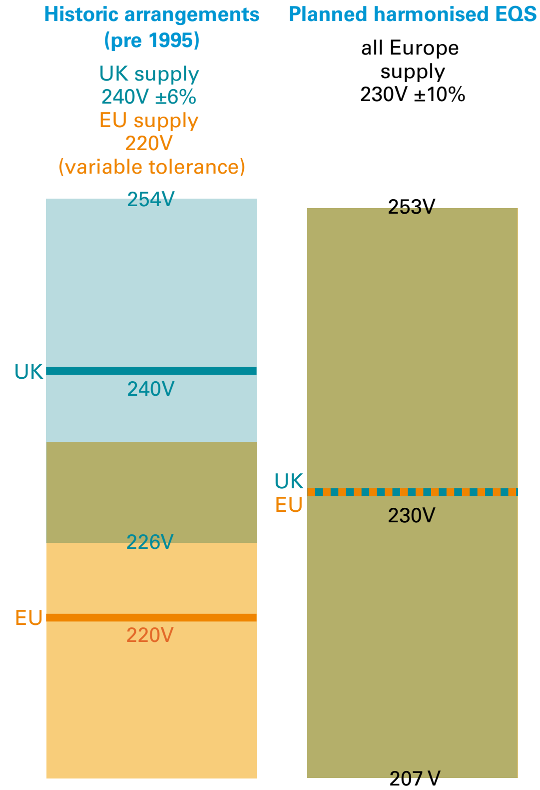
To simplify the market for electrical equipment further, the European Union has introduced the Low Voltage Directive (LVD) 2006/95/EC to regulate the normal operating voltage of electrical equipment to be supplied in Europe. Equipment that meets this standard bears the CE mark and is designed to operate with a nominal supply of 230V.

Electricity Quality and Supply Regulations (EQS) will harmonise supply voltages across Europe at 400/230V±10%, i.e. Vp within the range 207–253V (current guidance from DECC suggests this will happen in the UK during 2011/12). This means any piece of equipment with the CE mark can be safely operated on the local electricity supply anywhere in Europe.

Therefore in the UK, where supply voltages have historically been higher, equipment made for European markets is often used at a higher voltage than it is optimised for. As a result the equipment may be consuming more energy than is necessary. The following diagram illustrates the past and proposed voltage levels in the UK and the EU.

Note Electricity generation transmission and distribution is based on a three-phase alternating current (AC) system. For low voltage supplies the phases are connected in a 'star' arrangement are delivered using four wires – each of the three phases and the 'neutral' point between them. The nominal supply voltage in the UK is currently 400/230v, which means the voltage between the phases is 400V (often called line voltage), while the voltage between each of the phases and the neutral point is 230V often called phase voltage). In order to cope with the geographic layout of electricity distribution networks and the daily changes in electricity demand, electricity distribution network operators are allowed to provide phase voltages within the range 230v +10%/-6% i.e. between 216V and 253V (moving to 230V ±10%).

Figure 1 Impact of harmonisation of supply voltages across the EU



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How does voltage management work?

The theory of energy saving by voltage management relies on simple electrical formulae, which provide a relationship between electrical power consumption and voltage for a constant resistance.

Power demand (kW) can be expressed as a function of voltage:

$$Power = \frac{Voltage^2}{Resistance}$$

This means that for a simple linear resistive load the power consumed is proportional to the square of electricity supply voltage. Therefore the higher the supply voltage, the higher the energy consumption. Equipment that displays this characteristic can be described as 'voltage dependent'.

With a simple linear resistive load, a one per cent increase in supply voltage will cause a two per cent increase in power demand.

However, there are many different types of electrical load and most are not simple linear resistive. Modern electronic control equipment such as that used in ICT and high frequency lighting is designed to give a fixed output voltage irrespective of the supply voltage. They can be considered 'voltage independent'.

Other loads, such as electric motors, are partially voltage dependent. For a fixed speed motor, the power demanded by the load on the output shaft is often independent of supply voltage, but some of the losses which will result from operating the motor inefficiently are voltage dependent. The change in power demand for a one per cent change in supply voltage will therefore be between zero and theoretically two per cent. The exact proportion depends on the motor construction and its operating conditions.

Electricity supply companies charge for the energy supplied, measured in kilowatt-hours (kWh). These reflect the power consumed (kW) and hours of operation:

$$Energy = Power \times Time$$

To understand how much energy and cost you might save through voltage management, you need to understand what proportion of your electrical load is voltage dependant, what proportion is voltage independent and the number of hours each type of load operates for. The section "Understanding your load" explains in more detail how to assess which category your equipment falls into.

Safety warning – voltage management is not simply reducing voltage

Electrical equipment is designed to operate with an electricity supply that is within the range specified on its name plate. If the supply voltage is less or more than specified, the equipment may not operate correctly and could switch itself off, with possible safety implications.

When changing electricity supply voltages across a site, you will need to make sure that the supply is at an appropriate level. It shouldn't be so low that your equipment is supplied with a voltage lower than its rating, nor so high that you consume unnecessary amounts of energy.

Some sites may still have older equipment designed to operate on a supply voltage of 415/240V ±6%. This will need to be identified and taken into account in any voltage management project.

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Understanding your load

To determine whether voltage management could reduce your energy consumption, you will need to understand how much of the electrical equipment at your site is voltage dependent, and what proportion of your energy consumption that represents.

If a high proportion of electrical energy at your site is consumed by equipment where the power demand is to some degree voltage dependent, voltage management should reduce your consumption. But if your electrical consumption is mainly made up of voltage independent loads, you're not likely to be able to save much energy through voltage management.

It can be difficult to tell whether or not a specific item of electrical equipment is voltage dependent and close inspection will usually be needed. However, the following guidance should help.

To help access the potential for voltage management we need to categorise electrical equipment as either voltage dependent or voltage independent. These two groups are defined below.

Voltage dependent

A voltage dependent load is an electrical device whose power consumption varies with the voltage being supplied to it.

Example: tungsten filament lamp

An ordinary 40W tungsten filament lamp is a voltage dependent load. If the lamp is supplied at 230V, it is designed to draw 40W of power. Over eight hours it will consume 0.32 kWh.

The same lamp, supplied at 242V, will draw over 44W of power and in the same eight hour period consume 0.35 kWh – ten per cent more.

Note: For tungsten filament lamps, light output is also proportional to voltage.

Voltage independent

A voltage independent load is an electrical device whose power demand, within its designed operating range, is independent of supply voltage.

Example: Power supplies for ICT equipment

A power supply unit, such as those for laptop computers, is designed to give a fixed voltage output regardless of the supply voltage, allowing them to be used internationally. A typical unit gives a fixed output of 20V with a nominal input voltage of between 100-240V. The power supply to the computer is fixed, irrespective of the supply voltage to the power supply unit. The total energy demand of the computer and power supply will not change if the supply voltage varies.

Relationship between power and energy

In considering the energy efficiency and energy cost aspects of voltage management, it is important to understand the relationship between power and energy. Electricity suppliers bill us for the energy supplied. This will depend on the level of power needed and the length of time the equipment operates for.

For some systems with feedback control, often as simple as a thermostat, the amount of energy delivered remains the same, whatever the supply. As a result the system is effectively voltage independent even if the principle device has voltage dependent characteristics.

Example: electric kettle

A traditional electric kettle with a resistive element is a simple resistive load. Like a tungsten light bulb, it will consume more power if the supply voltage is higher than the nominal supply voltage.

However, bringing water to boiling point takes the same amount of energy, whatever the voltage. If the voltage is higher the kettle will just take less time to reach boiling point and switch off sooner. The fact that the kettle is thermostatically controlled means that it is, in practice, voltage independent.

The examples given here are intended to illustrate clearly the concept of voltage dependent and voltage independent loads and the relationship between power and energy. In practice most devices are more complex and their overall power demand will have multiple components that could be either voltage dependent or voltage independent. This is particularly true in the case of electric motors, whose construction, application, duty, efficiency and size can all influence the overall operating efficiency and the degree to which it is voltage dependent. *Figure 2* on the following pages discusses the voltage dependency of many common load types.

Figure 2: What types of equipment are voltage dependent?

Load type	Are they voltage dependent?	
Incandescent lamps	YES – Incandescent lamps (or bulbs) are a source of lighting where an electrical current runs through a filament that emits visible light. The most common types of incandescent lamps are standard tungsten filament, tungsten halogen and reflector lamps. All three of these are voltage dependent loads. Reducing the supply voltage to these lamps will result in a directly proportional reduction in power consumption. However, lower voltage and power will reduce the light output.	
Fluorescent lamps – inductive ballast (also known as switch start)	YES – An electrical ballast is required to strike (ignite) a fluorescent lamp. In older types an inductive (or magnetic) ballast is used. Simple magnetic ballasts provide an unregulated supply to the lamp with inductive and resistive impedance. In this arrangement the power consumed is proportional to the supplied voltage. However, lower voltage and power may reduce the light output. Rated light output is achieved within ±3% of 230V design voltage.	 Typically T8/T12
Metal halide/ SON lamps	POSSIBLY – These types of lamps have ballasts which can either be inductive or electronic. As per fluorescent lamps, depending upon the type of ballast, they can be either voltage dependent or voltage independent. The lighting supplier should be contacted to decide the type of ballasts you have and to determine their voltage dependency.	
Fluorescent lamps – electronic ballast (also known as high frequency)	NO – Modern fluorescent ballasts are electronically controlled to provide voltage at a higher than supplied frequency. This leads to improved efficiency in the production of light but also means they are voltage independent[1].	 Typically T5

[1] Electronic ballasts are usually classified into those with either "passive" or "active" front ends. Those with passive front ends use discrete electronic components whilst those with active front ends use integrated circuits. In either case the process of conversion from mains frequency to a higher frequency result in the power demand being voltage independent.

Load type	Are they voltage dependent?	
LED lamps	NO – LEDs have the same power demand, regardless of supply voltage, so energy consumed does not vary with voltage.	
Motor loads (Uncontrolled)	YES, IN MANY CASES – Most motors in use today are asynchronous induction motors. Large (>20kW) induction motors have low losses. When operating within 70-90 per cent of their rated output they are very efficient (as high as 95 per cent), and are effectively voltage independent. However, this is an ideal position. Most motors in use today are of a smaller rating and have higher losses making them less efficient. Many of these motors are oversized for their application and often operate for all or much of the time at partial load, which leads to increased losses. It is these losses which lead to a larger proportion of a motor's power demand being voltage dependent. If motor loads form a significant part of your total site load, you should complete a detailed technical evaluation into the savings potential.	
Motor loads controlled by variable speed drive (VSD)	NO – no additional energy savings are possible through the reduction of supply voltage.	

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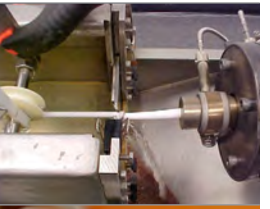
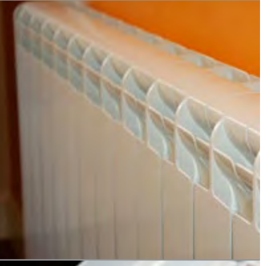
Load type	Are they voltage dependent?	
Process loads	POSSIBLY – Process loads are generally electronically controlled to ensure that processes operate correctly. Most of the energy consumed in process plant will usually be by motors and heating. The potential for energy savings through voltage management is therefore dependent on how loads are controlled. You will need to seek specialist advice to assess the likely benefits of applying voltage management to process loads.	
Electric heating	PROBABLY NOT – Electric heating is a resistive load and as such a higher supply voltage will result in an increase in power demand. However like the electric kettle (page 6), the method of control is critical to whether energy consumption increases with higher voltages. Where temperature controllers, such as thermostats, are installed and are set correctly, energy consumption will not change with an increased supply voltage. Instead instantaneous power demand will be higher and heaters will warm up quicker.	
Electronic loads and information and computer technology (ICT)	NO – Most electronic (i.e. low power) equipment is designed for world markets. For example computer power supplies, mobile phone chargers and office equipment can accept a wide range of input voltages while operating with fixed DC voltages. The majority of electronic equipment relies on regulated power supplies, which consume the same energy over a wide range of input voltages. The potential energy savings through voltage management are therefore negligible.	

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Voltage management techniques

Once you have determined if you can save by managing the supply voltage, you have three broad options available:

- **Install voltage management equipment** (this can be a site-wide or technology specific solution).
- **Adjust or modify incoming electrical supply infrastructure** (applies to sites supplied at high voltage only).
- **Replace voltage dependent loads.**

Install voltage management equipment

There are two types of voltage management equipment:

- fixed ratio which provides a fixed reduction at all times e.g. 10 per cent
- variable ratio which provides a constant voltage, regardless of load conditions, through continuous adjustment.

Your choice will depend on a number of factors, as discussed in the Practical considerations section. The device which suits you is best determined on a site-by-site basis through a technical and financial appraisal process.

Consider whether it makes sense to apply voltage management across your whole site. Products are available to manage voltage for specific loads and can be installed downstream of your main electrical incomer. These devices can be a useful alternative to the site-wide approach if only specific systems, such as lighting, can benefit from voltage management.

When voltage management equipment is introduced into an electrical supply, there can be some secondary power quality benefits in addition to the managed voltage. The operation of electrical equipment can be influenced by power quality issues such as harmonics, phase imbalance, power factor, and transients. Improvement of these issues may provide some further modest energy savings, however the magnitude of such savings is unlikely to have a significant impact on the business case for investing in voltage management equipment. A thorough analysis of power quality is required to substantiate or verify savings and if your site has noticeable power quality issues you should seek independent technical advice. Depending on the nature and severity of the problems a dedicated power quality solution may be required.

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Adjust or modify incoming electrical supply infrastructure

If your site is supplied at high voltage and you own the high voltage to low voltage transformer, you have a number of options to manage your voltage level.[2]

Tap down an existing transformer

Sites that are supplied at HV typically have one or more transformers to step voltage down to LV. Most transformers have tap changers installed to allow for manual ratio adjustment controlling site voltage. Tap changers typically offer a range of ±5% either in one per cent or 2.5% steps. The maximum reduction is limited by the range of the tap changer and its existing position.

Tapping down an existing transformer is a low cost option which can lead to a quick reduction in energy use. While it may not deliver maximum savings, it is certainly worth checking that your transformer hasn't been left in one of the 'higher' settings. Usually tap changers are 'off-load', which means that you will need to engage a senior authorised electrical engineer and contact your local electricity company to de-energise the transformer and make the adjustment.

Replace existing HV/LV transformer(s) (e.g. replace 11,000/415V with 11,000/380V)

It is likely that you have a transformer that is designed to provide a nominal phase voltage of 240V. If so, you could consider replacing this equipment with a unit offering a nominal voltage of 230V which would operate satisfactorily down to 207V.

If the transformer has been on site for some time, it could also have higher losses than a modern equivalent. It may also have a greater capacity than you currently need, along with a standard range of adjustment that would not allow it to benefit from the new voltage harmonisation.

A thorough review of your existing transformer(s), power demand and transformer ratings may show that changing the transformer(s) for correctly rated, wider tap range, low loss or super low loss equivalent designed to deliver a nominal 230V could be a highly cost effective option.

Energy savings from reduced transformer losses

Annual energy savings of close to £4,000 can be achieved through replacement of a standard loss 1000kVA Transformer with a super low loss equivalent. (Additional savings will be seen where secondary voltages can be reduced.)

In this instance these savings are attributed to a reduction in two types of losses:

i. Fixed core or iron loss, accounting for 19% of savings.

ii.Variable, dependent on load, copper loss, accounting for 81% of savings.

NB: Assumes transformer is permanently energised throughout the year and has a 75% loading and an electricity.

Click here to view Further transformer loss data.

[2] Note: Some sites take supply at low voltage but the DNO has the transformer that is dedicated to that site. In this instance it would be worthwhile for the site operator to approach the DNO with regards to tapping down the transformer.

Replacement of voltage dependent loads

Many voltage dependent loads are typically less efficient than voltage independent loads. An example would be fluorescent lighting, where you can improve efficiency by up to 40 per cent by changing from an older switch start ballast fitting to a modern high-frequency fitting[3] or LED. If older voltage dependent fluorescent lighting is a large proportion of your site load, you may want to consider replacing the existing lighting equipment with modern high-frequency lighting, which is voltage independent[4]. This type of project could deliver proportionally larger energy savings, especially when coupled with other energy efficiency measures such as daylight dimming and occupancy detection.

If you are undertaking energy efficiency projects on a site where voltage management has already been installed, it is likely that there will be some overlap of potential savings. The cumulative benefits of both projects will therefore be less than the sum of the two individual projects, and it is worth making sure the likely savings are clear before making any investment decisions.

If partially or variably loaded and/or uncontrolled motors are causing unnecessary energy demand, you have a number of options:

- If a motor has a constant **partial load** it makes sense to review the size of the motor and replace it with one that matches the load.
- For **variable torque loads**, principally pumps and fans, excellent savings can be made by using variable speed drives with feedback control. For example, cool air demand could be matched to the air temperature in a building. When the requirement for cool air is low the motor speed can be decreased, leading to a reduced motor load and significant energy savings[5].
- For **fixed torque loads**, such as conveyors, inefficient operation can often be eliminated by stopping the drive when it is not required. For example, installing detectors to stop a baggage handling system drive running when it is not needed can reduce the operating hours of the motors and reduce energy use.

Replacing motors or fitting drives may result in much bigger savings for the individual motor than can be delivered through at-source voltage management. However, this option may not realise the same overall savings when the whole site is considered.

Therefore a full and thorough financial appraisal of your all options with regard to replacement of voltage dependent loads should be carried out before you decide if voltage management is the most effective solution for your organisation.

[3] Under EC Regulation No. 245/2009 and implementing Directive 2005/32/EC. The least efficient ballasts are phased out in 2010 (C and D types) and all magnetic types by 2017.
[4] The same principle would apply to some other voltage dependent loads such as incandescent lamps which can often be effectively replaced with higher efficacy and lower energy LED solutions.
[5] Power demand is a function of speed cubed and a 10% reduction in speed will result in a x% reduction in power demand.

Evaluating the potential for voltage management

To find out whether you can save energy from voltage management, a site survey should be carried out and the potential energy savings calculated. A suitably qualified electrical engineer should be appointed to carry out any measurements and load assessment on electrical infrastructure.

Steps for the survey are:

- A: Measure voltage and power
- B: Measure voltage drops across the site
- C: Determine the proportion of energy consumption that is voltage dependent
- D: Identify any critical loads
- E: Calculate potential energy savings
- F: Decide power rating of voltage management equipment.

Figure 3: Site survey steps

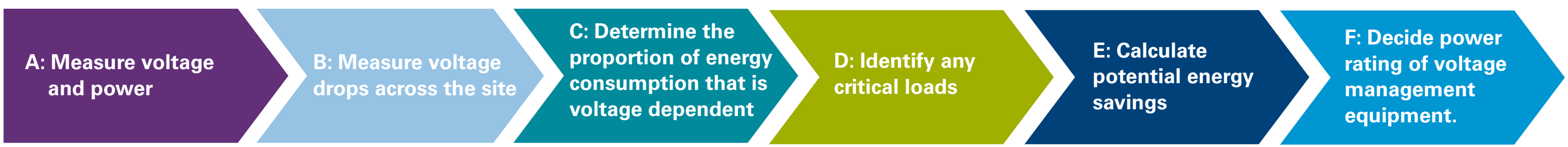

Figure 4: Technical considerations

A: Measure voltage and power	B: Measure voltage drops across the site	C: Determine the proportion of energy consumption that is voltage dependent

A: Measure voltage and power

What should you measure?

The voltage level at the incoming supply point(s) of a site should be logged to determine the maximum and minimum voltages, showing how voltage varies over time and with changing power demand.

The voltage and current for all phases should be logged and the total power calculated to give an indication of how supply voltage and power demand interact.

The data from the logger should be used to calculate the lowest operating voltage on the site to determine a suitable reduction in voltage.

When and how long should you measure it for?

Logging should be carried out for a minimum period of seven days and recorded as averaged at five or ten minute intervals. This should be performed when the operation of the site is expected to be typical rather than at a time of low electricity demand. Longer duration logging may be required for sites with different operational profiles.

Loggers of this type need to be installed by qualified personnel.

Why is the minimum and maximum voltage important?

The resultant data will allow the minimum and maximum voltages to be determined. This will allow the potential percentage voltage reduction to be identified and determine whether fixed or variable ratio equipment is most suitable.

B: Measure voltage drops across the site

What is the voltage drop and why is it important?

Between the incoming supply point and electrical equipment supplied within a site there will be a reduction in voltage. This is due to the size and length of electrical cabling and the amount of power being transmitted. This 'voltage drop' should be no more than that recommended in the Wiring Regulations.

If you're considering voltage management it's important to make sure that the electricity supply to all electrical devices is always within their stated operating conditions. To ensure that this is the case, you need to know the maximum voltage drop that occurs across the site.

When and how should voltage drop be measured?

Voltage drop only occurs when power is being transmitted. It is therefore essential that the circuits being measured are loaded – in other words you should take measurements when the site is in normal use.

Voltage drop is measured by simultaneously logging the voltage at the incoming supply, and taking comparison measurements of voltage at various points around the site. The maximum voltage drop should be calculated as a percentage of the incoming voltage.

You may notice particularly high voltage drops in outlying circuits such as car park lighting. These may limit the maximum voltage reduction that can be made without alterations e.g. changing the cabling arrangements to the car park.

C: Determine the proportion of energy consumption that is voltage dependent

What proportion of the energy consumption is voltage dependent?

To determine how much energy you are likely to save through voltage management, you'll need to assess how much of your energy use voltage dependent equipment is responsible for.

How do you determine what is voltage dependent versus voltage independent?

As a starting point, it's useful to establish your site's average electricity demand profile. You can do this by looking at the profile obtained from the voltage logger and comparing it with any half hour data[6] you have to ensure that the logger profile is representative of site demand. You'll also need to check that the adopted profile takes issues such as seasonal variations into account.

The next step is to carry out a walk round survey to identify the type of loads present at a site; whether they are voltage dependent or independent, their size and operating hours.

From this information you will be able to develop a 'bottom-up' load profile, banded by voltage dependent and voltage independent loads that you can compare with the average actual profile previously determined. The more accurately the profile emerging from the walk round survey matches the actual load profile, the more accurate your savings estimate will be.

[6] Many sites have half-hourly electricity meters and electricity suppliers are obliged to provide customers with the resulting half hourly data. It is very useful to compare a full 12-month data set with that resulting from the power logger, you can check the annual maximum demand in kVA, which may occur at a particular time of year to ensure that any equipment you buy will be adequately rated to supply this demand and you can check for average demand in KW for use in the savings calculations.

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D: Identify any critical loads

Why is it important to identify critical loads?

It is important to identify any safety or business critical electrical equipment such as IT infrastructure, process or medical equipment, or imported equipment that could be adversely affected by a reduction in voltage. Before making any changes you'll need to check that business critical electrical equipment will remain within the operating conditions specified by its manufacturer.

E: Calculate potential energy savings

How is this done?

You can calculate your potential energy savings from the potential voltage reduction, whether this is for a fixed or variable ratio VM device or a replacement transformer. and the proportion of the annual energy consumption that is voltage dependent.

For a **fixed ratio** voltage management device, the percentage energy saving will be the product of the annual energy consumption, the percentage by which the voltage can be reduced and the percentage energy saving per percentage voltage reduction. An example calculation showing the points to consider is given in the next section.

For a **variable ratio** voltage management device, the percentage energy saving is calculated differently to take into account the variation in percentage voltage reduction which is linked to variations in supply voltage.

For a replacement transformer the savings from reduced losses can be calculated as described on page 10. Savings from voltage reduction can be calculated as for a fixed ratio voltage management device.

F: Decide power rating of voltage management equipment

Why is sizing of equipment important?

Undersized equipment will run hot and eventually fail, possibly with significant consequences, while oversized equipment will introduce unnecessary losses and could be needlessly expensive. It is important to use the 12 months of half-hourly data to get the correct size of unit that will supply the site's maximum demand (kVA). Don't forget to also factor in any known growth plans for the site.

Safety notice

THE CONNECTION OF VOLTAGE LOGGING EQUIPMENT AND MEASURING VOLT DROPS ACROSS THE SITE IS A POTENTIALLY HAZARDOUS TASK. IT SHOULD BE CARRIED OUT BY APPROPRIATELY QUALIFIED STAFF, ONCE A FULL RISK ASSESSMENT HAS BEEN COMPLETED, AND IN ACCORDANCE WITH AN AGREED METHOD STATEMENT THAT ADDRESSES THE RISKS.

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Calculating the energy savings

The energy savings that result from voltage management are the product of:

1. The power demand and operating hours
2. The percentage voltage reduction
3. The percentage power reduction per percentage of voltage reduction

To illustrate the calculation methodology we will use a simplified, fictitious case study: Anywhere Admin Centre. The majority of the employees at the site work five days a week, but a number of critical departments and the powerful IT equipment operates 24/7. There are three principal types of loads on the site:

1. Mains voltage halogen lighting in the sales and communal areas – 20kW.
2. Older type fluorescent lighting in the office space – 50kW
3. ICT equipment – 30kW.
   Maximum load on the system is 100kW.

1. Power demand and operating hours

The first task is to look at the average weekly power profile and decide how many operating periods to divide each week into. Our case study presents a simple example with constant daytime and evening/weekend loads so two time bands are adequate – weekdays and evenings/weekends. In more complex operations you may need to break the day up into several time slots to get an accurate model. In our example, if the public areas of our building operate on a Saturday but most of the offices are closed then we would need to add an additional time band for Saturday daytime.

For each of these time periods it is important that you reconcile the measured maximum demand with the combined demand derived from the walkabout survey of the equipment

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operating at that time. Ideally these approaches should balance. If in our case study the logger indicated that the evening's load was, for example, 50kW, it would indicate that either we had underestimated the loads (more offices were lit overnight than we had thought) or missed something (10kW of car park lighting had been overlooked).

Step 1: Power demand and operating hours

The information from the walkabout survey is tabulated in time bands as set out below.

	Weekday day time (40hrs) load kW	Evenings & weekend (128hrs) load kW
Reception lights (mains voltage halogen)	20	0
Office lights (inductive ballast fluorescent)	50	10
ICT equipment	30	30
	100	40

2. Percentage voltage reduction

To calculate the possible voltage reduction you will need to know:

- your target minimum supply voltage
- the lowest normal supply voltage at the point of supply
- the maximum volt drop across the site.

From this information you can calculate the percentage voltage reduction you can apply.

3. Percentage power reduction per percentage voltage reduction

The power demand of a simple resistive load is:

$$Power = \frac{Voltage^2}{Resistance}$$

This means that for a simple resistive load a one per cent reduction in supply voltage will deliver a two per cent reduction in power and energy demand.

Most sites will have a mixture of different types of equipment which are either voltage dependent, voltage independent or partially voltage dependent. To calculate the impact of, say, a voltage reduction, we need to calculate for each time period an aggregate power reduction for each percentage reduction in the supply voltage.

Step 2: Percentage voltage drop

The facilities engineer responsible for the Anywhere Admin Centre has decided that he would like all equipment to have a minimum supply voltage of 225V. The supply voltage changes with the time of day. At night it can get as high as 250V while during the day a minimum voltage of 245V can be seen. The greatest voltage drop occurs on supplies to the top floor of the building. During the normal working day this can be 5V less than the point of supply.

The current lowest site voltage is 240V(245v less 5V), while the desired minimum voltage is 225V – so we have the potential to reduce the voltage by 15V or six per cent.

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Step 3: Percentage power reduction per percentage voltage reduction

The mains halogen lights are voltage dependent and the power demand of these lights will be reduced by two per cent for each one per cent of voltage reduction. These lights amount to 20 per cent of the daytime load which will be reduced by (2 x 20 per cent) = 0.4 per cent per one per cent voltage reduction. The ICT equipment is wholly voltage independent and will contribute no reduction.

Fluorescent (inductive ballast) lighting is partially voltage dependent (at least 90 per cent) and therefore we will get 90 per cent x two per cent = 1.8 per cent power reduction per one per cent voltage reduction. This load is 50 per cent of the overall site demand and contributes a further 1.8 per cent x 50 per cent = 0.9 per cent reduction in on site power demand as a result of a one per cent reduction in supply voltage.

The total figure for the site during the normal working day is 1.3 per cent reduction in power demand for a one per cent reduction in supply voltage.

Load		% dependency	% impact of 1% volt reduction	Demand kW	Proportion of load %	% site power reduction per % voltage reduction
Halogen lights (mains voltage)	Voltage dependant	100	2	20	20	0.4
Fluorescents (inductive ballast	Partially voltage dependant	90[7]	1.8	50	50	0.9
ICT equipment	Voltage independent	0	0	30	30	0.0
				100		1.3

At evenings and weekends the calculation is as follows:

Load		% dependency	% impact of 1% volt reduction	Demand kW	Proportion of load %	% site power reduction per % voltage reduction
Halogen lights (mains voltage)	Voltage dependant	100	2	0	20	0
Fluorescents (inductive ballast	Partially voltage dependant	90[8]	1.8	10	50	0.45
ICT equipment	Voltage independent	0	0	30	30	0.0
				40		0.45

[7] Clients may wish to contact OEMs to determine the exact power demand for change in voltage input.
[8] Clients may wish to contact OEMs to determine the exact power demand for change in voltage input.

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4. Calculating the energy and cost savings

Using the information you now have you can calculate the projected energy savings which are the product of:

- The power demand.
- The operating hours.
- The percentage voltage reduction.
- The percentage power reduction per percentage of voltage reduction.

For each time period you need to multiply the load (kW) by the length of the time period (hrs) by the percentage voltage reduction and the percentage power reduction per percentage of voltage reduction (Remember this is a ratio not a percentage and the number you use will be in the range 0-2).

Finally you'll need to consider other potential impacts.

Lighting equipment is designed to produce rated light output at the nominal supply voltage (in this case 230V). The light output will be reduced as a result of reducing the supply voltage. You'll need to check that lighting levels will not fall below recommended design levels as a result of reducing the supply voltage.

Some voltage management devices offer small additional energy savings benefits through their ability to improve the power quality. These potential benefits are specific to the quality of power on individual sites, so they'll need to be assessed and verified on a case-by-case basis.

The losses introduced by the voltage management device should also be taken into account. Whilst typically very low, especially for larger units, these losses will lessen the savings to a certain degree.

Once you have assessed how much you could save through voltage management, you can compare the benefits to those of alternative energy efficiency projects.

Part 4: Calculate the savings

Applying the values already determined, we get the following energy savings for our two time periods:

Load	Daytime (40 hrs/week)	Evening & weekends (128 hrs week)
Load KW	100	40
Operating hours	40	128
Weekly energy consumption kWh	4,000	5,120
% voltage reduction	6%	6%
% site power reduction per % voltage reduction	1.3	0.45
Weekly energy saving kWh	312	138

The weekly energy savings of 450 kWh represent a 4.9 per cent saving.

The site operates 52 weeks per year and pays 10p per KWh supplied, giving an annual cost saving of £2,340.

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Practical considerations

You will now have been able to assess the energy saving benefits of voltage management specific to your site. Before installing equipment there are a number of practical considerations to be taken into account:

Installation issues

You'll need to consider how much space new equipment will need, the best location for it, as well as taking into account the cabling and controls. Do you have a safe location for it, where it is adequately ventilated and there will not be any heat build-up or noise issues?

Transformer replacement

No additional space is required for this option as it is a direct replacement. An additional benefit is a new transformer with a projected 30-year life.

Annual maintenance

Does the equipment need to be regularly maintained, and if so has this been factored into the payback calculations? Voltage management equipment typically does not require maintenance, although it may be sensible to regularly check that it is set up to provide the optimum voltage, as the incoming supply could have changed.

By-pass switch

Do you want to install a by-pass switch to take the equipment off-line for replacement or maintenance? It may make future changes easier.

Fixed ratio or variable ratio?

Both options have their advantages, the **fixed ratio** device drops the voltage level by a set percentage regardless of incoming voltage and is less technically complex. **Variable ratio** devices provide a fixed output voltage by varying the percentage drop dependent on incoming voltage. This can minimise the risks of under-voltage and also improve the utilisation of a device.

Guaranteed savings

These offer assurances that the predicted saving will materialise against a given baseline. Saving guarantees should be supported by a baseline that has been determined through monitoring and supported by half-hourly metering. These should be agreed by both the client and the equipment provider, and backed up by a statement outlining the methodology used by both parties to resolve any disputes.

Efficiency of voltage management equipment

Different options may have differing levels of efficiency. Some equipment needs additional auxiliary equipment to maintain operation. You'll also need to think about the efficiency of the voltage management equipment to maximise the benefits.

Safety first

Work on electrical systems should be left to a suitably qualified person.

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Glossary

DNO
Distribution Network Operator – the organisation responsible for the local electricity supply cables and infrastructure.

Harmonics
Some electrical equipment, such as variable speed drives and regulated power supplies, can impose electrical interference or 'harmonics' on the electricity supply. This can cause interference with other equipment and cause slightly increased losses within transformers other electromagnetic equipment. Site operators are obliged to keep harmonics within specified limits.

HV
High voltage – an alternating current supply voltage in excess of 1000V. In the UK the majority of sites with a HV supply voltage will be supplied at voltage of 11,000V (11kV).

LV
Low voltage – an alternating current supply voltage less than 1000V. An LV supply in the UK from the DNO is currently 400V three phase or 230V single phase +10% -6%. Moving to ±10% in 2011/12.

Phase balancing
Commercial and industrial premises are provided with a three-phase electricity supply, which is necessary for many electric motors. Most electrical equipment requires just a single phase supply. Where single phase equipment is installed on a site with a three-phase supply, it needs to be shared or 'balanced' across the three phases. If this is not the case the imbalance can, in the extreme, cause three-phase equipment, such as motors, to operate inefficiently or incorrectly.

Power factor
The ratio of useful power to total power as drawn from an AC supply by an electrical device or installation. In most instances a poor power factor is caused by the magnetising power required by equipment such as electric motors. The cables within electricity supply networks and on sites need to deliver the total power (useful and magnetising power). Poor power factor can reduce the capacity of cables, etc, to deliver useful power.

Power Factor Correction (PFC)
Since poor power factor reduces the capacity of a DNO's network to deliver useful power, most electricity tariffs are structured to penalise sites with a poor power factor. There is often a good payback to be had by fitting PFC to improve the power factor at a site. Power factor penalties are only an issue for larger consumers, so you should check with your supplier if you are charged a penalty for this. For more information on PFC, refer to Carbon Trust Technology Guide CTG007.

Impedance
A measure of the opposition to the flow of an alternating current in a circuit; the aggregation of its resistance, inductive and capacitive reactance.

Inductance
A measure of the inertial property of an electrical device caused by the magnetic field created that opposes the flow of an alternating current through the device.

Transient voltages
Transient voltages are very short duration spikes caused by switching and faults on the electricity network. In extreme cases these can cause catastrophic damage to equipment. Smaller transients can shorten the life expectancy of electrical equipment.

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The Carbon Trust is a not-for-profit company with the mission to accelerate the move to a low carbon economy. We provide specialist support to business and the public sector to help cut carbon emissions, save energy and commercialise low carbon technologies. By stimulating low carbon action we contribute to key UK goals of lower carbon emissions, the development of low carbon businesses, increased energy security and associated jobs.

We help to cut carbon emissions now by:

- providing specialist advice and finance to help organisations cut carbon
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We reduce potential future carbon emissions by:

- opening markets for low carbon technologies
- leading industry collaborations to commercialise technologies
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0800 085 2005

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