GLOSSARY OF TERMS

Active power	See useful power
Apparent power	See total power
BMS	Building management system
BEMS	Building energy management system
Capacitor	An electrical device that can compensate for the effect of reactive power caused by inductive loads
Data logger	A means of recording a site's electrical profile – Sinergy's product is the e-Tracker
DNO	Distribution network operator
Embedded carbon	The direct and indirect carbon emitted for the entire production process or any item
Harmonics	Troublesome voltages at multiples of the mains frequency (50Hz) that can be introduced into an electricity supply by the presence of certain equipment, including inappropriately specified PFC equipment
Line filter	A device that 'smooths' the mains voltage to reduce the prominence of harmonics. A line filter is sometimes used in conjunction with PFC equipment to ensure there are no harmonic generation issues
LVD	Low Voltage Directive (LVD) 2006/95/EC
MCCB	Moulded case circuit breaker
Power factor	The ratio of useful power to total power, as drawn from an AC supply by an electrical device or installation. Power factor can also be expressed as the cosine of the angle that exists between total power and useful power vectors
Power factor correction (PFC)	A technique to compensate for poor power factor and thereby optimise the transfer of useful power into electrical equipment
Reactive load	A load characterised by the presence of an inductance or capacitance, such as is present in induction heaters, motors, fluorescent lights and welding sets. It consumes reactive power as well as useful power

Reactive power	Power that is consumed by the reactive nature of a device, yet produces no useful work; can be either inductive or capacitive and is measured in kvar
Resistive loads	A purely resistive load possesses no reactance, that is, it draws no reactive power and therefore has a power factor of 1 (or unity). Examples of resistive loads are incandescent lighting and resistive heating elements
Total power	Also known as 'apparent' power. The total power drawn by a device or installation, including that consumed by its reactive nature; units in kVA (thousands of Volt Amps)
Transformer	An electrical device that can increase (step up) or reduce (step down) any given voltage
TRVs	Thermostatic radiator valves
Unity	A term sometimes used to describe ideal power factor ratio that is 1
Useful power	Also known as 'active' power. Power that is consumed by a device when doing useful work. Note that, depending on the efficiency of the device itself, not all of the useful power is actually converted to work
VSD	Variable speed drive
Voltage optimisation (VO)	A technique to manage incoming voltage and lower it to a level more suitable for electrical appliances
Voltage dependent	Equipment, fittings and devices whose consumption will vary according to the voltage level supplied to them. They will be able to perform their function to within the manufacturers' specification
Voltage independent	Equipment and fittings designed to operate at a fixed voltage level regardless of the voltage level supplied. Therefore their power supply is fixed irrespective of the supply voltage level

VOLTAGE OPTIMISATION

Voltage optimisation is a well-established, proven technology that manages incoming voltage and reduces it to a level more suitable for electrical appliances. In the UK, the average electricity supply is approximately 242Volts, which is high compared to other countries.

Electrical appliances with the CE mark must be capable of working across a wide voltage range; anywhere between 207-253Volts.

253V	**Maximum that electricity should be supplied**
242V	**Average level at which voltage is supplied**
216V - 220V	**Ideal voltage to maximise equipment efficiency**
207V	**The lowest voltage level that electricity should be supplied**

WHAT IS VOLTAGE OPTIMISATION?

How does voltage optimisation work?

Using transformer technology, voltage optimisation reduces incoming mains voltage to a level that allows electrical equipment to operate more efficiently. The level that voltage is reduced by is dependent on many factors: incoming mains voltage level, site load dynamics and the transformer ratio setting within the voltage optimiser itself.

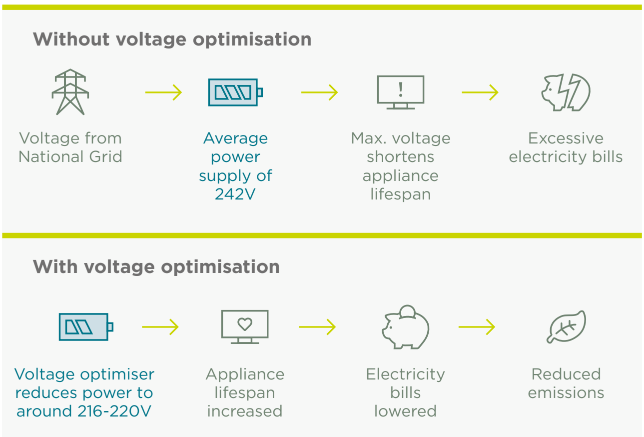
The need for voltage optimisation

Supplying electrical appliances at higher than 220Volts wastes energy. The extra voltage is converted to unwanted heat or vibration. This can also reduce the life expectancy of appliances.

Why voltage optimisation is ideal for the UK

The European Union has introduced the Low Voltage Directive [LVD] 2006/95/EC to regulate the normal operating voltage of electrical equipment. Equipment that meets this standard bears the CE mark and is designed to operate with a nominal supply of 230Volts +/-10% (207Volts – 253Volts).

Voltage optimisation systems reduce (or 'step down') the incoming voltage to reduce the kW used. This is possible because electricity in the UK is supplied at around 242Volts; significantly higher than required by equipment bearing the CE mark. Besides wasting power, over-voltage also forces equipment to run towards the top end of its tolerance, reducing life expectancy and incurring higher maintenance costs.



WHAT IS VOLTAGE OPTIMISATION?

The effect of high voltage levels

There are two main types of electrical devices; voltage dependent and voltage independent (see page 18 for more details). It is important to understand the load dynamics of your site to ensure that voltage optimisation is appropriate (see page 14 for more details).

The following examples explain the impact of differing voltage levels on an incandescent lamp and an electric kettle.

Incandescent lamp – voltage dependent

When receiving higher voltage levels, the lamp will be brighter and subsequently hotter than optimum. It may therefore fail before reaching its designed life expectancy. At the lower voltage level, e.g. 220Volts, the lamp will emit a level of light that it was designed for and as a result, will last longer.

Electric kettle – voltage independent

When receiving high voltage levels a kettle will boil water faster than it is designed to. The oversupply of voltage may reduce its life expectancy. Lowering the voltage will lengthen the time it takes to boil water, but it will increase the kettle's life expectancy.

TRANSFORMERS EXPLAINED

A transformer is an electrical device that can increase (step up) or reduce (step down) voltage.

Transformers are versatile and highly reliable devices used to provide voltage transformation from the 230Volts +/- 10% mains supply. They are constructed from insulated, high purity copper turns or windings, wrapped around a core of electrical grade silicon steel. The ratio of turns in the windings is directly proportional to the voltage rating of each winding. By varying the turns, it is possible to achieve any desired output voltage.

Transformers are specified by the VA rating, which is the combined product of voltage and current rating for all outputs.

Key elements of a transformer

1. Winding: Transformers have two windings or coils. The primary winding is fed power from the source and the secondary winding feeds the transformed voltage to the load or appliance.

2. Core: The core provides a controlled path for the magnetic flux generated within the transformer.

3. Input connections: The input is known as the primary side, this is where the electrical supply that is to be changed is connected.

4. Output connections: The output side of a transformer is known as the secondary side, this is where the electrical power is fed to the load. In voltage optimisation installations, this is where the reduced voltage is fed to the distribution board(s).

Transformer efficiency

An efficiently designed transformer minimises the power losses that give rise to unwanted heat. Excessive losses can cause the temperature of the transformer to rise to unsafe levels.

Transformer losses come from two sources: the electrical resistance of the copper windings and losses within the steel core. The steel core is the most critical element in good transformer design. Modern silicon steels allow operation at higher operating flux densities. This reduces the number of windings required, keeping copper losses and heat to a minimum.

Fixed (single tap) v variable (multi tap) ratio technology

A number of factors need to be considered before deciding what type of transformer is most appropriate for the site.

A fixed ratio transformer sets the level that voltage will be reduced by. For example, if the incoming mains supply is 242Volts, with a fixed ratio transformer set at 0.91 ratio (9%), the voltage will be reduced to 220Volts. The reduced voltage level will track the incoming supply (see graph on page 10) as it fluctuates and consistently reduce it by 0.91 ratio.

Variable ratio transformers work in a similar way to fixed ratio transformers. However, the ratio can be manually changed, should the mains voltage supply level change significantly. Variable ratio transformers allow the future-proofing of a voltage optimiser and maximise potential energy savings.

What is the expected lifespan of a voltage optimiser? See page 25

TRANSFORMERS EXPLAINED

Types of transformers

Transformers are configured based on the application and number of phases on the electricity supply.

Single-phase supply

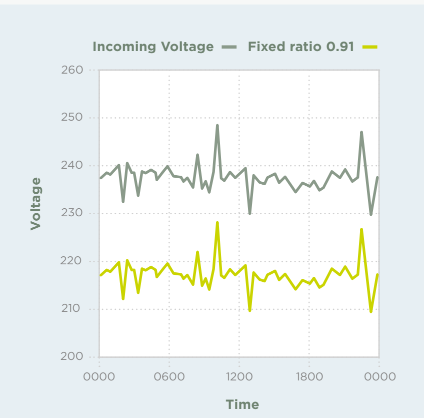
Mainly used in domestic properties, single-phase transformers offer greater versatility than three-phase transformers, having primary and secondary windings constructed in two equal parts. These two parts can then be reconnected in either series or parallel configuration.

Three-phase supply

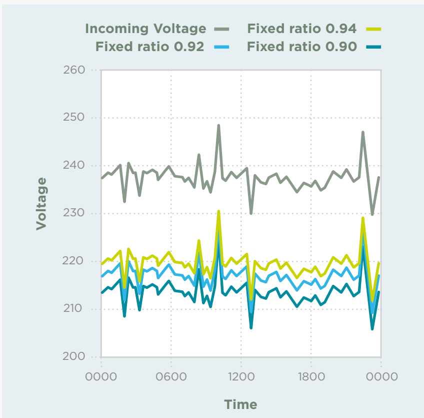
Power supplied through a three-phase circuit allows for the use of 3x single-phase transformers or a single three-phase transformer. Both methods are equally valid, but at higher power levels, a single three-phase transformer is often a cheaper solution.

Fixed v variable transformers

Both types of transformer reduce voltage levels. Variable ratio level transformers allow the ratio to be changed manually.



Fixed ratio transformer



Multi-tapped ratio transformer

Transformers used in voltage optimisation

There are two main types of transformers used in voltage optimisation to step down voltage, autotransformers and toroidal transformers. Both types are perfectly suitable for voltage optimisation. It is simply down to manufacturer product design as to which is used in their voltage optimisation solution.

Toroidal transformers

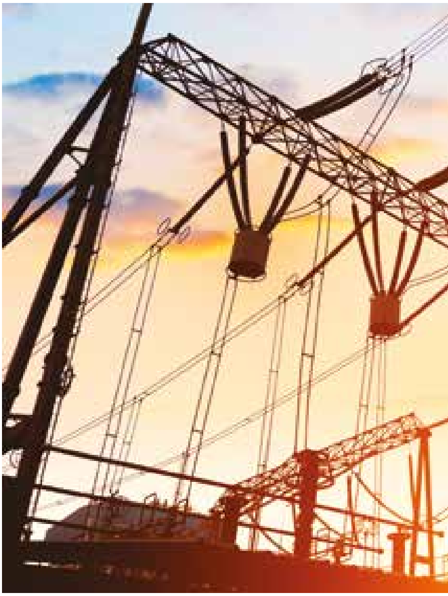
Toroidal transformers provide considerable benefits over traditional lamination construction transformers. Low loss silicon steels in continuous strip format provide up to 50% savings on weight and volume, and energy savings of around 60%. Toroidal transformers also provide easier and more flexible mounting options, reduced stray field due to the absence of butt gaps between laminations and greater flexibility in dimensions for a given power rating.

Autotransformers

An autotransformer is a tapped, winding transformer that changes the voltage that is available locally to the voltage required by a particular load.

With autotransformers there is one winding, a portion of which is common to both the primary and the secondary circuits. In other words, the primary and secondary coils have some or all windings in common.

With a single-tapped winding, an autotransformer is generally preferable to an isolation transformer with two separate windings, for numerous reasons. It is much smaller and lighter than an isolation transformer and also has better voltage stability and greater overload tolerance.



OHM'S LAW

Ohm's law

Voltage optimisation can be explained using Ohm's Law:

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

Power (P) = Kilowatts (kW)

V = Voltage in volts (V)

R = Resistance in Ohms (Ω)

These calculations are based on a constant resistance (R) of 20 Ohms (Ω), a non-optimised voltage (V) of 242V and an optimised voltage of 220V, with a unit cost of electricity of £0.10/kWh

Non-optimised supply

$$\text{Power (P)} = \frac{242\text{V} \times 242\text{V} \ (\text{V}^2)}{20\Omega \ (\text{R})}$$

$$2928\text{W (P)} = \frac{58{,}564\text{V}}{20\Omega \ (\text{R})}$$

$$2.928\text{kW} = \frac{2928\text{W}}{1000}$$

£0.10/kWh x 2.928kW = £0.2928/h

£0.2928 x 24hrs = **£7.03/day**

Optimised supply

$$\text{Power (P)} = \frac{220\text{V} \times 220\text{V} \ (\text{V}^2)}{20\Omega \ (\text{R})}$$

$$2420\text{W (P)} = \frac{48{,}400\text{V}}{20\Omega \ (\text{R})}$$

$$2.42\text{kW} = \frac{2420\text{W}}{1000}$$

£0.10/kWh x 2.42kW = £0.242/h

£0.242 x 24hrs = **£5.81/day**

Save £1.22 a day or 17.4%

The above calculations and percentage savings are for example purposes only. Please note, savings will vary depending on power supply and electrical appliances used.

CE MARKING

In 2006 the European Union 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 230Volts +/-10%.

Any electrical equipment that does not carry a CE mark or predates 1995, should still operate correctly with voltage optimisation equipment however we recommend that it should be checked with the manufacturer of the appliance to ensure it complies with the LVD.

The CE marking system was introduced in 1995 to serve three main purposes:

- To show that the manufacturer has checked that these products meet EU safety, health or environmental requirements
- As a key indicator of a product's compliance with EU legislation
- To allow the free movement of products within the European market

UNDERSTANDING LOAD DYNAMICS

Every site is different, which means the level of savings will vary. However, any facility that uses electrical equipment and lighting should consider voltage optimisation to reduce carbon footprint and energy bills.

Checks should be made to establish the existing mains voltage supply level. Whilst the UK supply is typically around 242Volts, some sites could be lower and therefore voltage optimisation may not always be suitable.

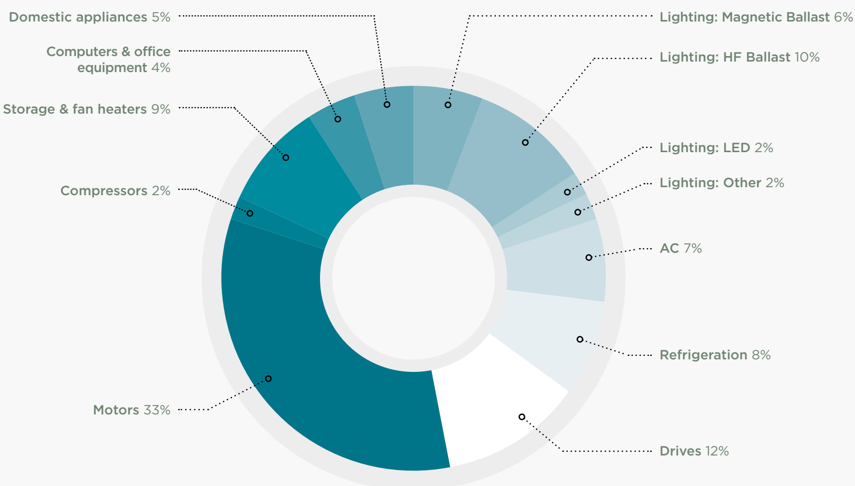
Understanding a site's load dynamics

To understand whether voltage optimisation is appropriate, a site's load dynamics should be analysed. This is to gain a full understanding of the type of appliances and their power consumption in relation to the total load.

Site summary

Lighting	20%
Motor loads	62%
Heating	9%
Other appliances	9%
Total	**100%**

Example power consumption in relation to a site's total load



RESISTIVE LOADS

Resistive loads

Resistive loads consume electrical energy in a sinusoidal manner. This means that the current flow is in phase with, and directly proportional to, the voltage (the voltage and current are in phase, the power factor is in unity).

A resistive load contains no inductance or capacitance, just pure resistance. Therefore, when a resistive load is energised, the current rises instantly to its steady-state value, without first rising to a higher value.

Incandescent lighting and electrical heaters are examples of applications using this type of load.

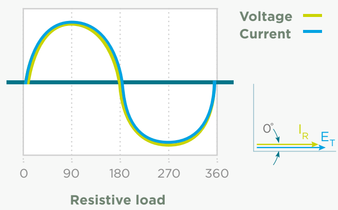
Incandescent lamps and bulbs

Incandescent lamps produce light by passing an electric current through a filament in a vacuum. The resistance of the filament causes it to heat up and the electrical energy is converted to light and thermal (heat) energy.

Electric heaters

An electric heater works in the same way. Its resistance converts the electrical energy to thermal energy.

Real power



INDUCTIVE AND CAPACITIVE LOADS

Inductive loads

An inductive load pulls a large amount of current (an inrush current) when first energised. After a few cycles or seconds, the current 'settles down' to the full-load running current.

The changing voltage and current in an inductor are out of phase. As current rises to a maximum, the voltage falls. Inductive loads can cause excessive voltages to appear when switched.

Motors and transformers are examples of applications using inductive loads:

Motors: Two sets of magnetic fields in an electric motor oppose each other, forcing the motor's shaft to spin.

Transformers: A transformer has two windings, a primary and a secondary. The magnetic field in the primary winding induces an electric current in the secondary winding.

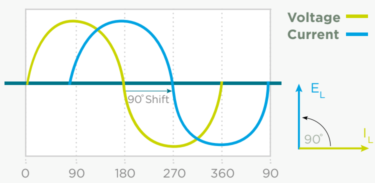
Capacitive loads

A capacitive load is an AC electrical load, in which the current wave reaches its peak before the voltage.

The current waveform is leading the voltage waveform; therefore, the voltage peaks and current peaks are not in phase. The amount of phase delay is given by the cosine of the angle (Cos) between the vectors representing voltage and current.

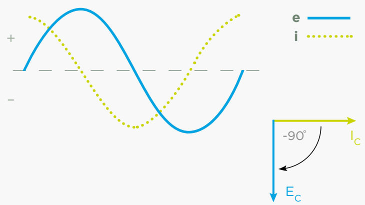
Examples of capacitive loads are; camera flashes, radio circuits and power supplies.

Reactive power



Inductive load

Capacitive load



MIXED/COMBINATION LOADS AND VOLTAGE DROP

Mixed/combination loads

Domestic and industrial installations use a mixture of resistive, inductive and capacitive loads; no two installations are ever the same.

The mixed/combination loads within installations make it difficult to calculate precise savings. To date, there is no agreed method to accurately make these calculations.

When measuring demand, the output will show only the mixed load resultant and not a breakdown of resistive, inductive and capacitive load types. Having an understanding of how the loads types are split proportionally within an installation does help in estimating savings. This is one of the questions to be determined for any site.

Examples in various installations:

Bakery:

- Ovens – Resistive loads
- Lighting – Resistive/inductive loads

Machine/production workshop:

- Machine motors – Inductive loads
- Lighting – Resistive/inductive loads

Call centre:

- ICT equipment – Resistive/inductive/capacitive loads
- Lighting – Resistive/inductive loads

Domestic dwelling:

Kitchen

- Oven – Resistive loads/inductive
- Microwave oven – Inductive/capacitive
- Lighting – Resistive/inductive loads

Living room

- Lighting – Resistive/inductive loads

Bedrooms

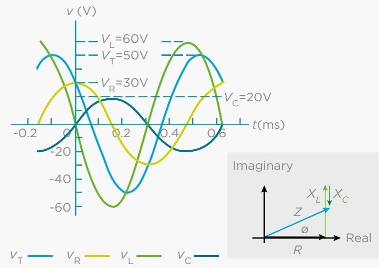
- Lighting – Resistive/inductive loads

Bathroom

- Power shower – Resistive/inductive/capacitive loads
- Lighting – Resistive/inductive loads

The diagram below shows the three loads types VR, VL and VC overlaid, and their sum total VT. The phase angle may be positive or negative depending on whether the overall voltage leads or lags the current in the circuit. This, combined with fluctuations in voltage and varied appliances, gives an insight in to why it is so difficult to measure exact savings.

Combination electrical loads



Voltage drop

BS 7671 states that voltage drop between the origin of an installation and any load point should not be greater than 3% for a lighting circuit and 5% for a power circuit. This is achieved by selecting the correct installation method, along with the correct size conductor.

As part of any site survey, voltage drop should be measured across the site. This then needs to be taken into account when calculating and determining the output voltage level that a voltage optimiser will be delivering to the site. Allowing for voltage drop ensures that equipment at the furthest point on the site will still be supplied at an appropriate level.

VOLTAGE DEPENDENT AND INDEPENDENT DEVICES

Electrical equipment is generally either voltage dependent or voltage independent.

Voltage dependent

The power consumption of voltage dependent equipment will vary according to the voltage level supplied to it. It will be able to perform its function to within the manufacturers' specification. Voltage dependent equipment benefits most from voltage optimisation.

Voltage independent

Voltage independent equipment is designed to operate at a fixed voltage level regardless of the level supplied. Therefore their power supply is fixed, irrespective of the supply voltage level.

By determining the types of electrical equipment, and their proportion of a site's total load, you can then evaluate the potential benefits of voltage optimisation. A higher proportion of voltage dependent equipment means greater savings and quicker return on investment.

Examples of voltage dependent and independent devices

Equipment & Fittings	Explanation	Are savings achievable with VO?
Lighting		
Incandescent lamps	Voltage dependent	✔✔✔✔✔
Fluorescent lamps (with inductive ballast/switch start)	Voltage dependent	✔✔✔✔✔
Metal halide lamps	Voltage dependent	✔✔✔✔
Fluorescent lamps (with electronic ballast/high frequency)	Voltage independent	✗
Motor loads – fixed speed motors		
Moulding machinery	Voltage dependent	✔✔✔
Extrusion machinery	Voltage dependent	✔✔✔✔
Robots	Voltage dependent	✔✔✔
Water pumps	Voltage dependent	✔✔✔✔
Air conditioning	Voltage dependent	✔✔✔✔
Refrigeration	Voltage dependent	✔✔✔✔
Circular saws	Voltage dependent	✔✔✔✔
Escalators	Voltage dependent	✔✔✔✔
Lifts	Voltage dependent	✔✔✔✔
Motor loads – fixed speed motors		
Motor loads (controlled by variable speed drives)	Voltage independent	✔
Heating		
Electric heating	Voltage independent	✗
Ground source heat pumps	Voltage dependent	✔✔✔
Air source heat pumps	Voltage dependent	✔✔✔
Electronics		
Televisions	Voltage independent	✗
Computers	Voltage independent	✗
White Goods		
Washing machine	Voltage dependent	✔✔✔
Tumble dryer	Voltage dependent	✔✔✔
Refrigerators	Voltage dependent	✔✔✔✔
Freezer	Voltage dependent	✔✔✔✔
Oven	Voltage independent	✗
Microwave	Voltage dependent	✔✔✔

DOES VO WORK FOR ALL INDUSTRIES?

The majority of industries have a need for lighting, IT equipment, refrigeration and general electrical appliances. Therefore, most will benefit from using voltage optimisation. Analysing a site's load dynamics is key to determining the potential savings opportunity that voltage optimisation could deliver.

The table below is an indicative guide, we have made estimates as to the proportion of the load that would/wouldn't work well with voltage optimisation to indicate overall financial viability.

Industry examples and indicative savings

Industrial sector	Examples of equipment	Are savings achievable with VO?
Agriculture, Forestry and Fishing		
Saw mills	Motors, lighting	✔✔✔✔✔
Dairy farming	Motors, pumps, lighting	✔✔✔✔✔
Fishing industry	Motors, pumps, lighting	✔✔✔✔✔
Mining and Quarrying		
	Motors, lighting, pumps	✔✔✔✔✔
Manufacturing		
	Moulding presses	✔✔✔
	Extrusion machinery	✔✔✔✔
Bakery production	Ovens	✗
Electricity, gas, steam and air conditioning supply		
	Motors, pumps	✔✔✔✔
Water supply and waste management		
	Pumps, motors	✔✔✔✔
Construction		
	Diggers, pneumatic drills, bulldozer, cherry picker	✗
Wholesale and retail trade; repair of motor vehicles and motorcycles		
	Lighting, IT, motors	✔✔✔✔✔
Transportation and storage		
	Lighting, motors	✔✔✔✔✔
Real estate		
	Lighting, IT, motors (AC/refrigeration), heating	✔✔✔

Table continued opposite

Industry examples and indicative savings (continued)

Industrial sector	Examples of equipment	Are savings achievable with VO?
Hotels and restaurants		
Hotels	Air conditioning, refrigeration, electronics, heating, pumps, lighting	✔✔✔✔
Restaurants	Air conditioning, refrigeration, electronics, heating, lighting	✔✔✔
Information and communication		
Offices	Electronics, air conditioning, lighting, vending machinery	✔✔✔✔
Data centres	IT servers	✗
Financial services		
Offices	Electronics, air conditioning, lighting, vending machinery	✔✔✔✔
Professional, scientific and technical activities		
	Lighting, motors, pumps, heating, IT	✔✔
Administrative and support service		
Offices	Electronics, air conditioning, lighting, vending machinery	✔✔✔✔
Public administration and defence		
Prisons	Accommodation, workshops, lighting, heating	✔✔✔✔
Education		
Schools	Vending machines, lighting air conditioning, swimming pools, ICT	✔✔✔✔
University Halls	Lighting, heating, electronics, domestic use	✔✔✔
Health and social work		
Hospitals	Lighting, motors, refrigeration, heating, IT	✔✔✔
Care Homes/Nursing Homes	Lighting, motors, refrigeration, heating, IT	✔✔✔
Arts, entertainment and recreation		
Theatres	Lighting, air conditioning, audio	✔✔
Recording studios	Lighting, electronics	✔✔
Leisure centres/Gyms/Sports arena	Lighting, motors, pumps	✔✔✔✔
Theme parks	Roller coasters / rides (motors), lighting, pumps	✔✔✔✔

PHASE BALANCING

Voltage optimisation is not the answer to phase balancing. Installing voltage optimisation equipment will not have any positive or negative impact on balancing the load.

A full site audit/survey will identify the load dynamics of a site and highlight any phase imbalance – this should be carried out as a matter of good practice. If voltage optimisation is a suitable solution, then as part of the installation process it is worth considering balancing the load evenly across the phases.

Why balance load across the phases?

When the load is not balanced across the phases, out of balance current will flow in the neutral conductor of the system. The result is power loss through the neutral conductor and potential increased heating of the cables. Voltage optimisation will not rectify this; re-balancing of loads across phases on site is the only solution to this.

Energy companies have a maximum demand charge, so balancing the load across the phases will reduce the maximum demand, and thereby reduce energy charges.

Overall load 1600Amps

L1 = 500Amps, L2 = 1000Amps and L3 = 100Amps

Charged against the 1000Amps on L2

Overall load 1600Amps

L1 = 535Amps, L2 = 525Amps and L3 = 540Amps

Charged against the 540Amps on L3