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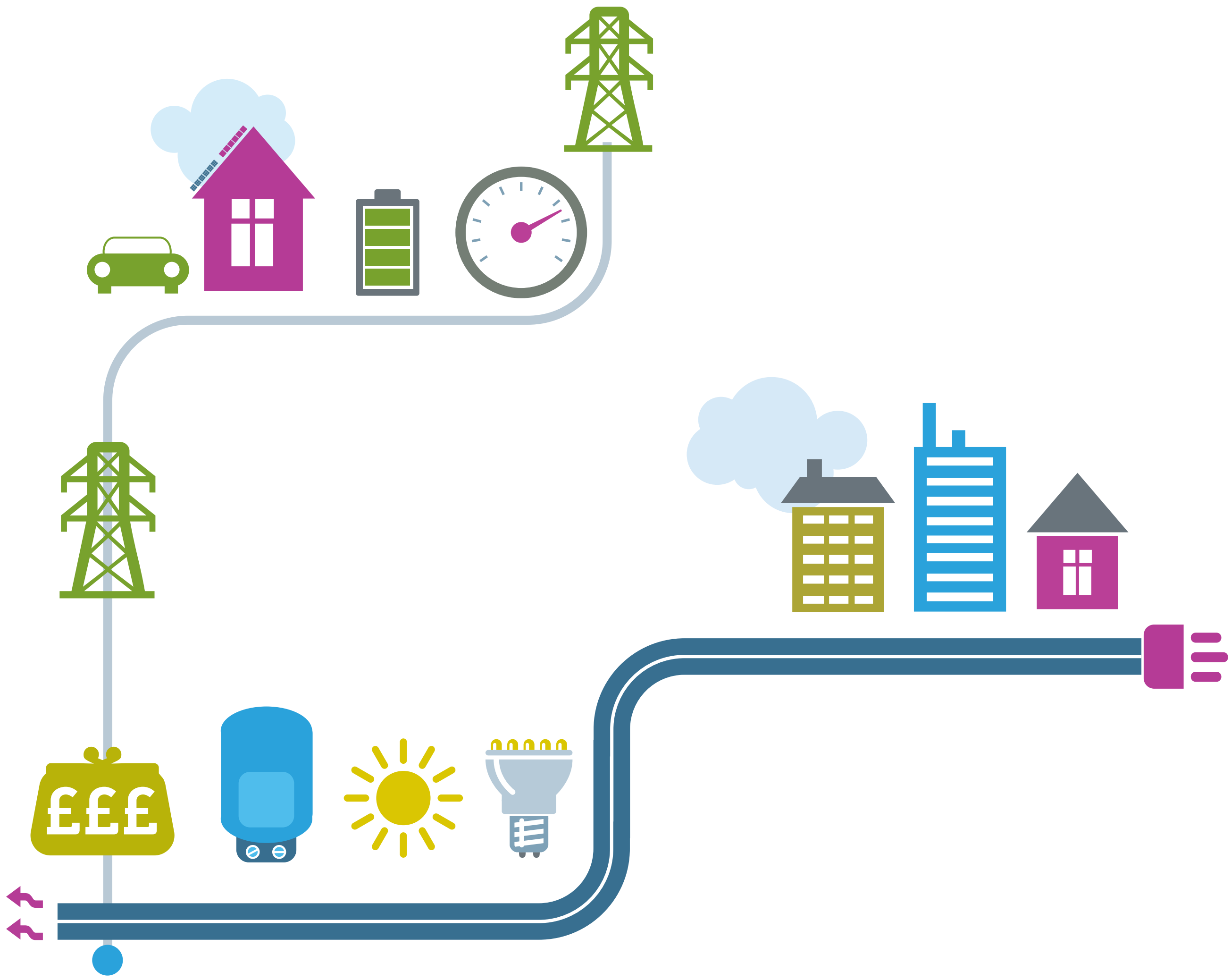
A GUIDE TO VOLTAGE OPTIMISATION SYSTEMS

Designed specifically for energy efficiency



COMPANIES INVOLVED IN THE PREPARATION OF THIS GUIDE

Save & Protect with EnergyAce

PES POWER EFFICIENT SYSTEMS LTD

EnergyAce is a trading name of Power Efficient Systems Ltd

eco-max VOLTAGE OPTIMISERS

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100% British Engineered. 100% Guaranteed Results.

We also recognise the input into this Guide from The Carbon Trust

CONTENTS

TERMS AND DEFINITIONS

Voltage Optimisation System	Equipment designed to reduce the system voltage within a Domestic Property or a Non-Domestic Property in order to reduce energy consumption, excluding Isolating Transformers.
Optimisation Bypass	A mechanism for disconnecting the Voltage Optimisation function with no interruption to the existing electrical supply
System Bypass	A mechanism for electrically disconnecting and isolating the Voltage Optimisation Unit from the electrical circuit and reconnecting the electrical supply
Domestic Property	A self-contained unit designed to accommodate a single household excluding buildings containing exclusively rooms for residential purposes such as nursing homes, student accommodation or similar.
Non-Domestic Property	A site or property that is not a Domestic site or property
Static Voltage Optimisation System	A system that delivers a fixed percentage reduction in voltage and whose output can be adjusted only when electrically isolated.
Dynamic Voltage Optimisation System	A system whose output can be adjusted without interruption to the load.
Dynamic Voltage Optimisation System with Stabilised Output Voltage	A system whose output can be adjusted to an agreed set output voltage without interruption to the load
Grid Voltage	Upstream of Voltage Optimisation System
System voltage	Downstream of Voltage Optimisation System

INTRODUCTION

BEAMA is the leading trade association that represents manufacturers of electrical infrastructure products and systems from transmission through distribution to the environmental systems and services in the built environment.

We work with our members to ensure their interests are well represented in the relevant political, regulatory and standardisation issues at UK, EU & international levels and our vision is that member products provide a sustainable, safe, efficient and secure UK electrical system.

There's a lot going on in the electrical industry that involves the infrastructure of the electrical network from generation, transmission to the point of use.

The government is signed up to reductions in carbon emissions and needs solutions. We've seen the introduction of a host of new renewable energy sources, the roll out of smart meters, more sophisticated energy control and the move towards the connected homes environment.

With a host of new products and technologies introduced to meet the demand for energy management and control, it is important that the quality of energy supplied is maintained and for this reason BEAMA has set up a Power Quality Group which looks at product sectors like Power Factor Correction, Voltage Optimisation, Harmonic Conditioning and Surge Suppression.

These product areas are also part of the solution for providing improved energy efficiency in domestic, commercial and industrial markets and, as the more sophisticated electrical infrastructure takes shape, will play an increasingly important role.

Take for example the area of Voltage Optimisation.

In the UK the declared electricity supply is now 230V with a tolerance of +10% to -6%. This means that the supply voltage can theoretically vary from 216.2V to 253V. Voltage Optimisation is an electrical energy saving technique that is installed in series with the electricity supply to provide a reduced supply voltage for the site's equipment.

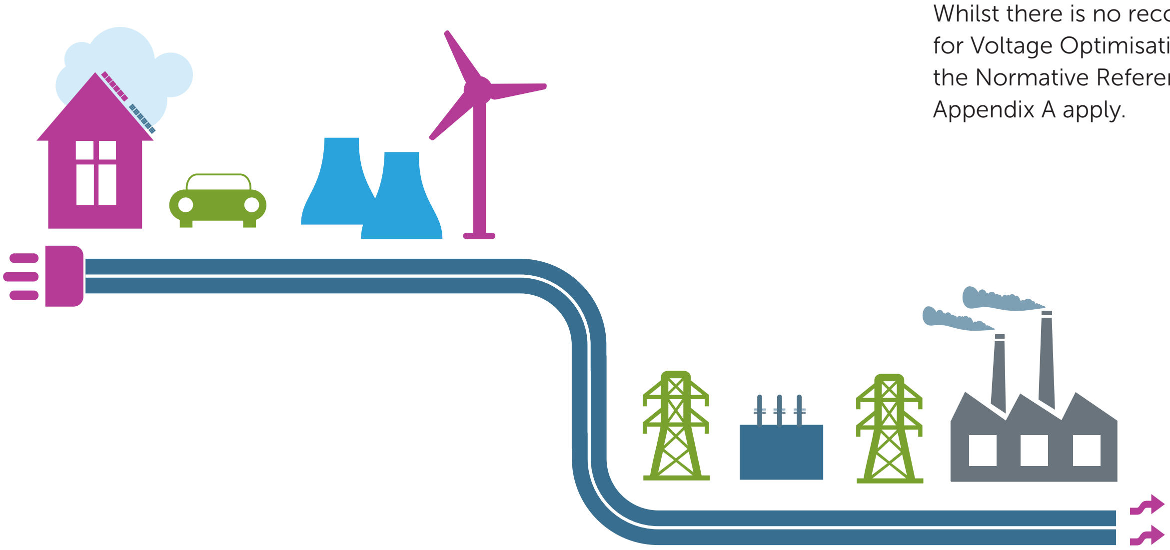
In some units Voltage Optimisation can improve power quality by balancing phase voltages and filtering harmonics and transients from the supply.

By efficiently bringing supply voltages to the lower end of the statutory voltage range, voltage optimisation technology could yield average energy savings of around 13%.

BEAMA is working with its' Voltage Optimisation members to illustrate where the best results for these products can be achieved and how they form another element of the bigger energy efficiency picture.

This Guide is a collaborative document between the leading UK manufacturers of Voltage Optimisation products. It is designed to show the best practice in determining the design, manufacture, assembly, installation, maintenance and servicing of Voltage Optimisation Systems for domestic properties and non-domestic properties.

Whilst there is no recognised Standard for Voltage Optimisation Equipment, the Normative References in Appendix A apply.



1
WHAT IS VOLTAGE MANAGEMENT?

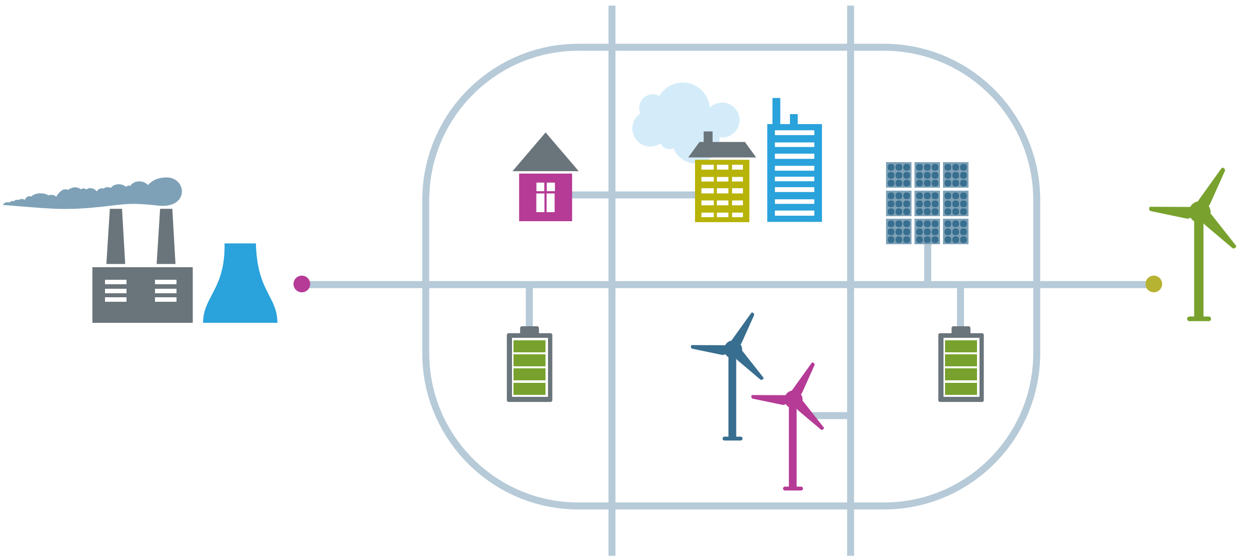
Voltage management is an umbrella term covering various distinct technologies, including voltage optimisation, voltage stabilisation, voltage regulation or voltage reduction. In the context of this document, we have used the term to maintain an impartial position with regard to equipment selection.

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

The basic principal of all voltage management equipment is to change the voltage level from that of the incoming grid supply to obtain the desired level. This may be to correct for situations such as over-voltage, under-voltage or phase imbalances.

There are a number of technologies available and various specifications of voltage management equipment.

One form of Voltage Management specifically designed for reducing energy consumption is Voltage Optimisation.



2
WHAT IS VOLTAGE OPTIMISATION?

The basic principal of all voltage optimisation equipment is to reduce the voltage level from that of the incoming grid voltage specifically to give energy savings. To achieve this change in voltage level, a low voltage, series connected transformer is required. The design of the Voltage Optimiser is such that it only transforms the amount of energy required to optimise the voltage. This makes it inherently more efficient than an isolating transformer that transforms the whole site load.

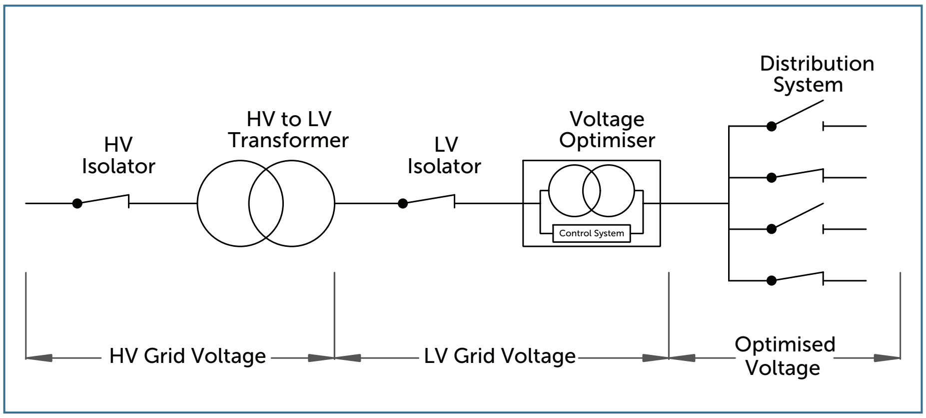


FIGURE 1: TYPICAL VOLTAGE OPTIMISATION INSTALLATION

Electrical equipment can sometimes consume more energy at higher voltages. Voltage Optimisation 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 – by the equipment connected to the distribution system.

2
WHAT IS VOLTAGE OPTIMISATION?

2.1 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. 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 nominal Design Voltage. 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.

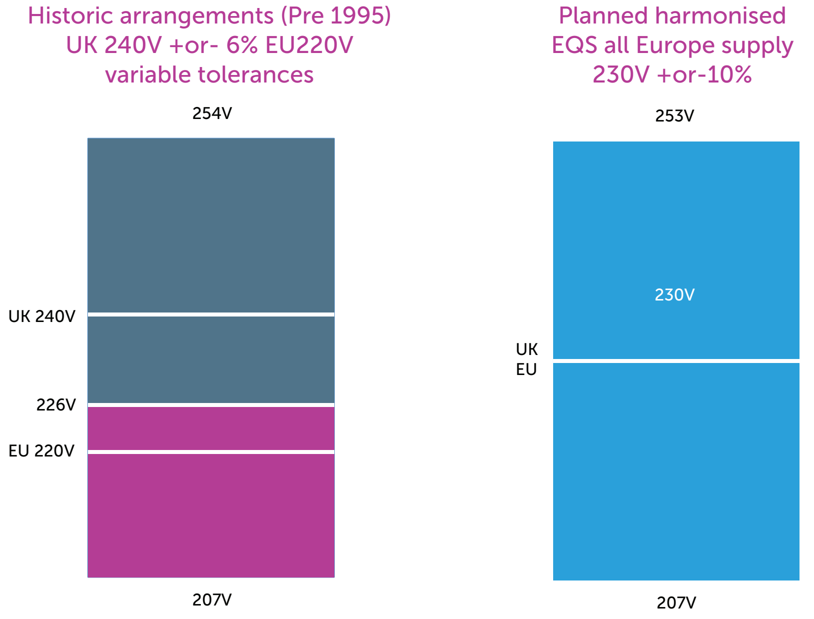


FIGURE 2: IMPACT OF HARMONISATION OF SUPPLY VOLTAGES ACROSS THE EU

2
WHAT IS VOLTAGE OPTIMISATION?

2.2 How does Voltage Optimisation work?

The theory of energy saving by Voltage Optimisation 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, as a rough 'rule of thumb' a one per cent increase in supply voltage will cause a two per cent increase in power demand.

WHEN CHANGING ELECTRICITY SUPPLY VOLTAGES ACROSS A SITE, YOU WILL NEED TO MAKE SURE THAT THE SUPPLY IS AT AN APPROPRIATE LEVEL.

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 Information & Computer Technology and high frequency & LED lighting is designed to give a fixed output 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). This reflects the power consumed (kW) and hours of operation:

$$Energy = Power \times Time$$

To understand how much energy and cost you might save through voltage optimisation, 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 The Load" explains in more detail how to assess which category your equipment falls into.

2.3 Safety Warning – Voltage Optimisation 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 Grid supply voltage of 415/240V $\pm$6%. This will need to be identified and taken into account in any Voltage Optimisation project.

3
TECHNICAL REQUIREMENTS

3.1 Considerations

A Voltage Optimisation System is designed for use in either a Domestic Property or Non-Domestic Property.

3.2 Design and manufacture

The design, manufacture, and assembly of a Voltage Optimisation System should be in accordance with BS EN ISO 9001:2008 and BS EN ISO 14001:2004.

3.3 Product enclosures

A Voltage Optimisation System shall comply with BS EN 61439-1:2011, Section 8.

3.4 Nameplate

The nameplate of a Voltage Optimisation System shall comply with BS EN 60076-11:2004, Section 7.1 and BS EN 61439-1:2011, Sections 5 and 6.1 with the addition of a unique serial number or batch number.

3.5 Non-hazardous materials

A Voltage Optimisation System shall comply with the relevant national regulations, legislation, and rules applicable to where the Voltage Optimisation System will be installed.

4
UNDERSTANDING THE LOAD

To determine whether Voltage Optimisation 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 Optimisation 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 Optimisation. However, operating the equipment close to its fundamental design value may maintain the life expectancy in line with manufactures expectations.

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.

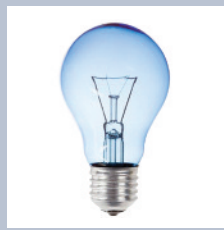
4.1 Voltage Dependent

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

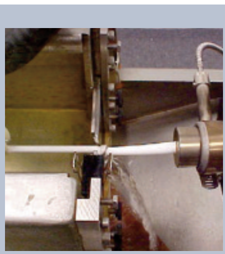
To help assess the potential for Voltage Optimisation we need to categorise electrical equipment as either voltage dependent or voltage independent. These two groups are illustrated below.

4
UNDERSTANDING THE LOAD

4.2 What type of equipment is voltage dependent?

Load Type	Are they voltage dependent?	
GLS Halogen energy saving lamps	**YES** – GLS Halogen lamps including the energy saving types also use filament technology like the old incandescent lamps where an electrical current runs through the filament that emits visible light. Halogen lamps run at a higher temperature making them more efficient than traditional lamps are. 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 slightly. Rated light output is achieved within $\pm$3% of 230V design voltage	
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 $\pm$3% of 230V design voltage.	
Metal Halide / SON lamps	**YES** – These types of lamps typically use an inductive or magnetic ballast in which case they are voltage dependent. 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].	
LED lamps - with Integrated Circuit based Driver	**NO** – Newer LEDs using IC based Drivers have the same power demand, regardless of supply voltage, so energy consumed does not vary with voltage.	

[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?
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. 
Process loads	**POSSIBLY** – Process loads are generally electronically controlled to ensure that processes operate correctly. Most of the energy consumed in process plants 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 reducing the voltage applied 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, 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 similar amounts of energy over a wide range of input voltages. The potential energy savings by reducing the applied voltage are therefore small to negligible. 

It should be borne in mind that operating the equipment close to its fundamental design value may maintain the life expectancy in line with manufactures expectations.

4 UNDERSTANDING THE LOAD

4.3 Evaluating the potential for voltage management

To find out whether you can save energy from Voltage Optimisation systems, 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 the 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 Optimisation equipment

4.4 Quantifying Results

Measuring and quantifying the results of Voltage Optimisation can be very difficult with dynamic loads. You cannot simply compare last month's bill without the Voltage Optimiser, with this month's bill with the Voltage Optimiser, as this does not take the variables into account.

Generally there are two methods for establishing the savings percentages:

The simplest option is for you to evaluate three month's worth of half hour data from before and after the installation of Voltage Optimisation whilst considering whether the site loading has changed. For example, you may have installed or removed equipment, changed your operating hours or experienced an increase in production levels; even the weather or other external influences may affect your electrical consumption. All these need to be considered when assessing the savings.

Another method would be to use a standard Measurement & Verification Protocol, to perform "on-off" tests under comparable load conditions and measure the differential in KW and/or kWh consumption between the connected equipment when supplied via grid voltage and optimised voltage respectively. Repeating this a number of times over a given period will provide "snap shot" comparisons of consumption with and without Voltage Optimisation. The average difference between the two figures is the percentage reduction in energy consumption, which can be used to extrapolate the savings over a year. To measure the savings in this way would ideally require a dynamic Voltage Optimiser which can "seamlessly" switch between the optimised voltage (Savings Mode) and grid voltage (Optimisation Bypass) under load conditions without interrupting the power to the connected equipment.

In practical terms a combination of both the above may be used, but the key is to agree the method employed with the Voltage Optimisation supplier in advance.

5
TYPES OF VOLTAGE OPTIMISATION EQUIPMENT

5.1 Static Voltage Optimisation System

A Static Voltage Optimisation System is one that delivers a fixed percentage reduction in voltage and whose output can be adjusted only when electrically isolated. Fluctuations in grid voltage will be mirrored in the optimised voltage.

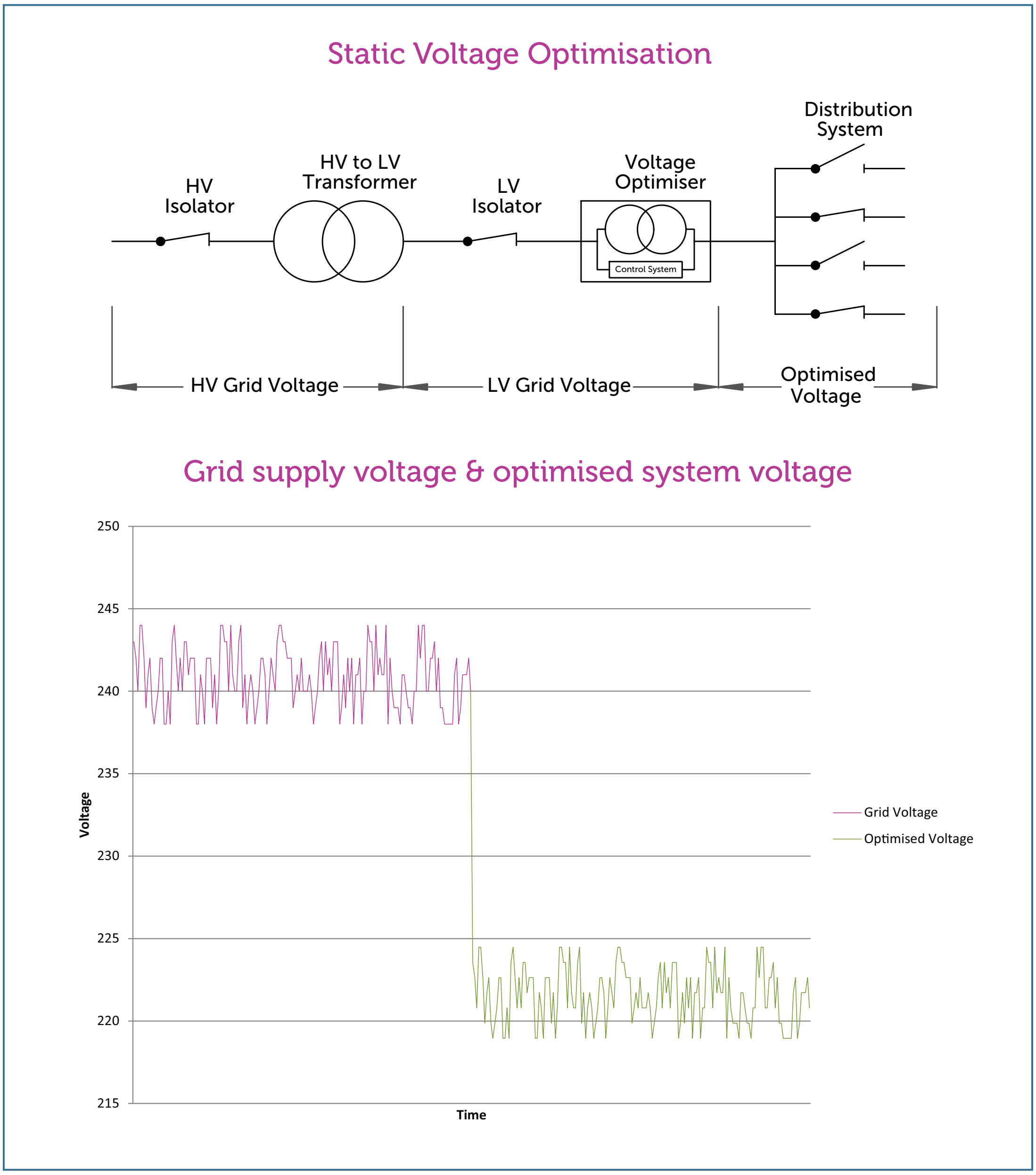


FIGURE 3: RESULT OF STATIC VOLTAGE OPTIMISATION WITH FIXED 8% REDUCTION

5
TYPES OF VOLTAGE OPTIMISATION EQUIPMENT

5.2 Dynamic Voltage Optimisation System

A Dynamic voltage Optimisation System is one whose output can be adjusted without interruption to the load. Typically the system offers a fixed reduction; fluctuations in grid voltage are mirrored in the optimised voltage whilst the grid voltage remains above a predetermined level. Below this predetermined level the Voltage Optimisation effect is bypassed to give the grid voltage without interrupting the supply to the site. This feature provides a guaranteed minimum optimised voltage. In both instances, site load is conducted through the Voltage Optimisation unit.

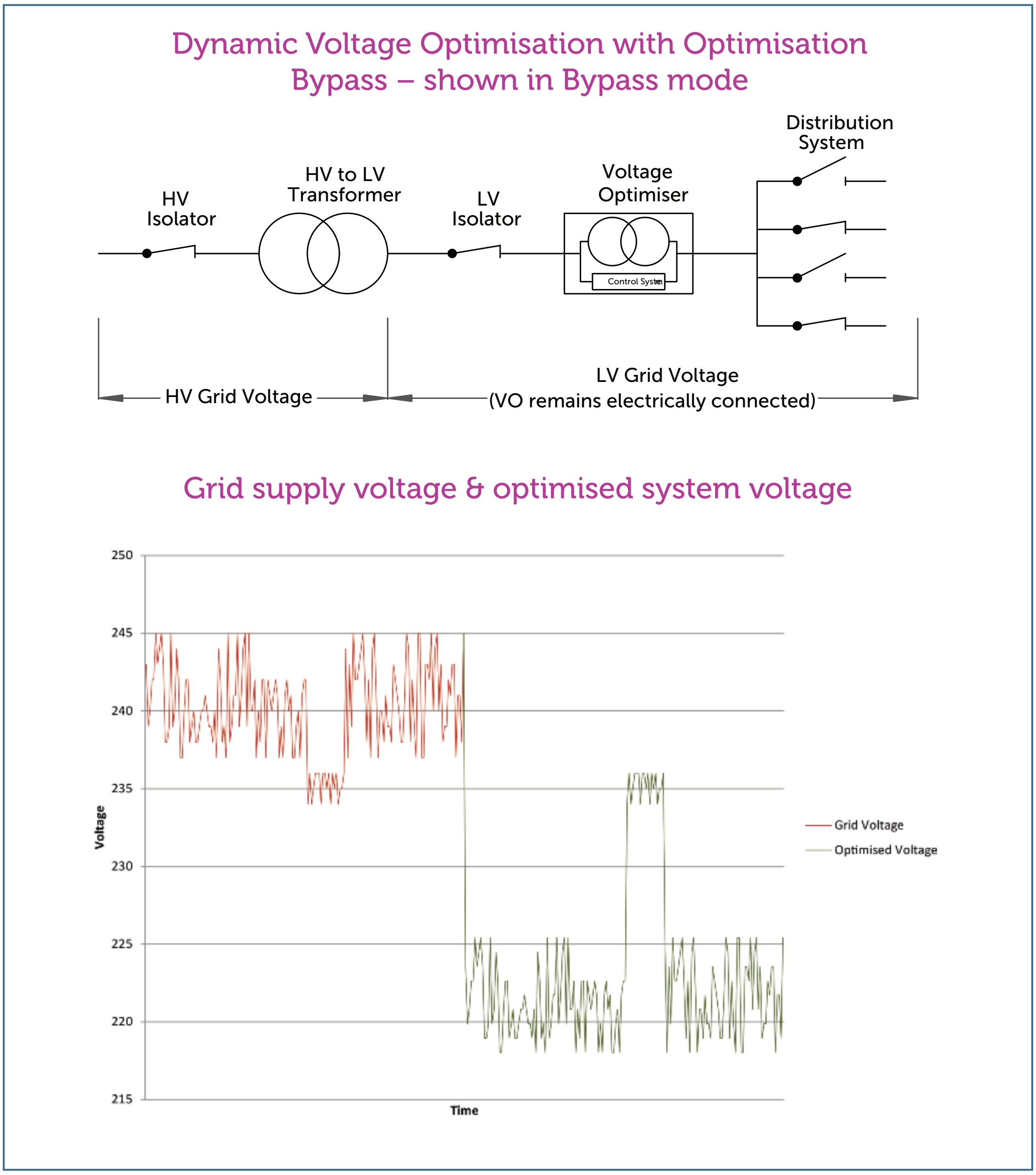


FIGURE 4: RESULT OF DYNAMIC VOLTAGE OPTIMISATION WITH A FIXED 8% REDUCTION AND SHOWING PERIOD OF OPTIMISATION BYPASS

5
TYPES OF VOLTAGE OPTIMISATION EQUIPMENT

5.3 Dynamic Voltage Optimisation System with Stabilised Output Voltage

A Dynamic Voltage Optimisation System with Stabilised Output Voltage is one whose output can be adjusted to an agreed set output voltage without interruption to the load.

Typically the system offers a variable reduction; fluctuations in grid voltage are removed from the optimised voltage. This feature provides a stabilised supply and a guaranteed minimum optimised voltage. In all instances, site load is conducted through the Voltage Optimisation unit.

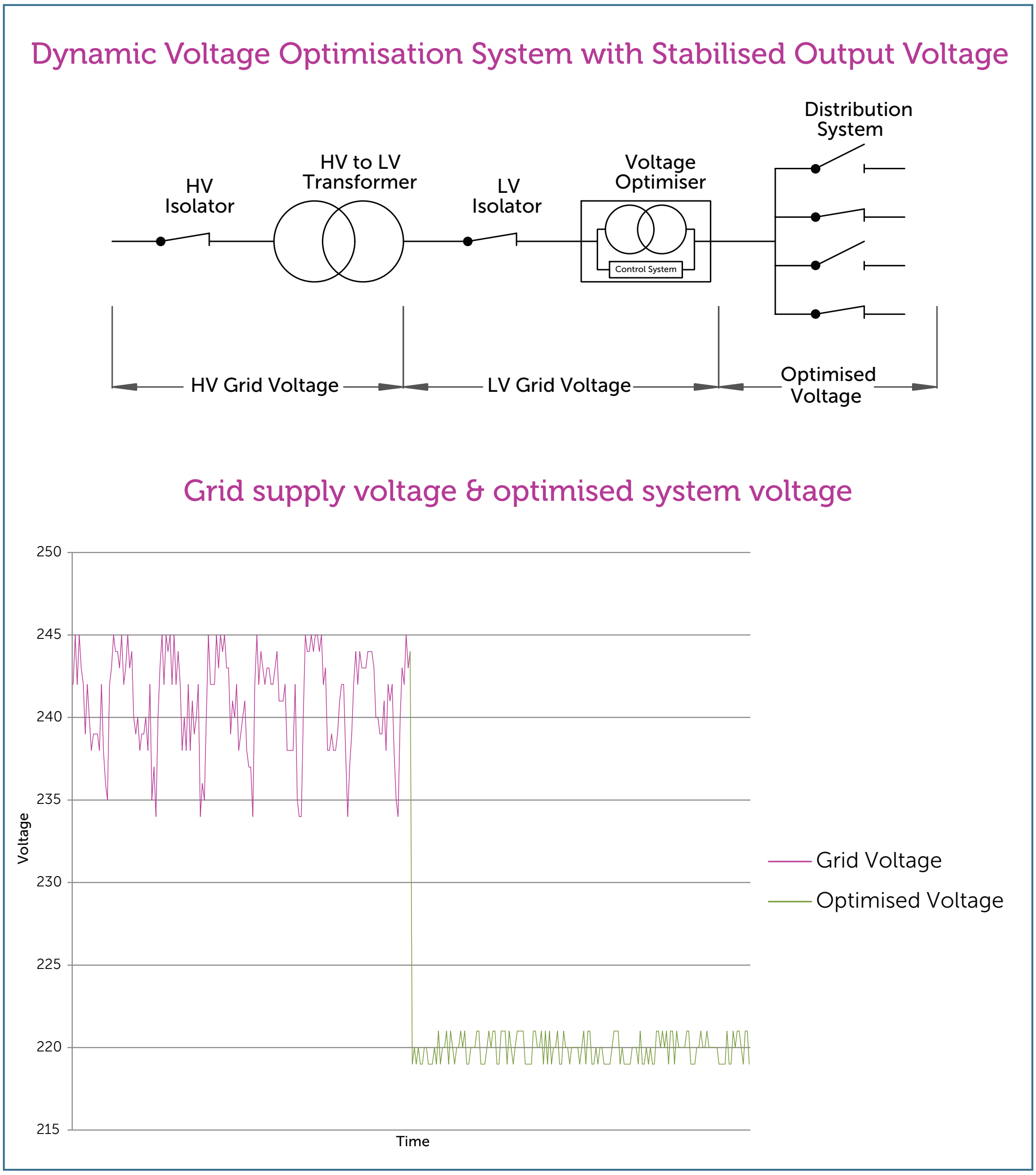


FIGURE 5: RESULT OF DYNAMIC VOLTAGE OPTIMISATION WITH A VARIABLE REDUCTION TO ACHIEVE A STABLE OPTIMISED VOLTAGE

5
TYPES OF VOLTAGE OPTIMISATION EQUIPMENT

5.4 System Features

Optimisation Bypass – a mechanism for disconnecting the Voltage Optimisation function with no interruption to the existing electrical supply as shown in Figure 4.

System Bypass – a mechanism for electrically disconnecting and isolating the Voltage Optimisation Unit from the electrical circuit and reconnecting the electrical supply. In all instances, the site load is conducted through the bypass mechanism with the Voltage Optimisation unit being electrically isolated in the bypass state.

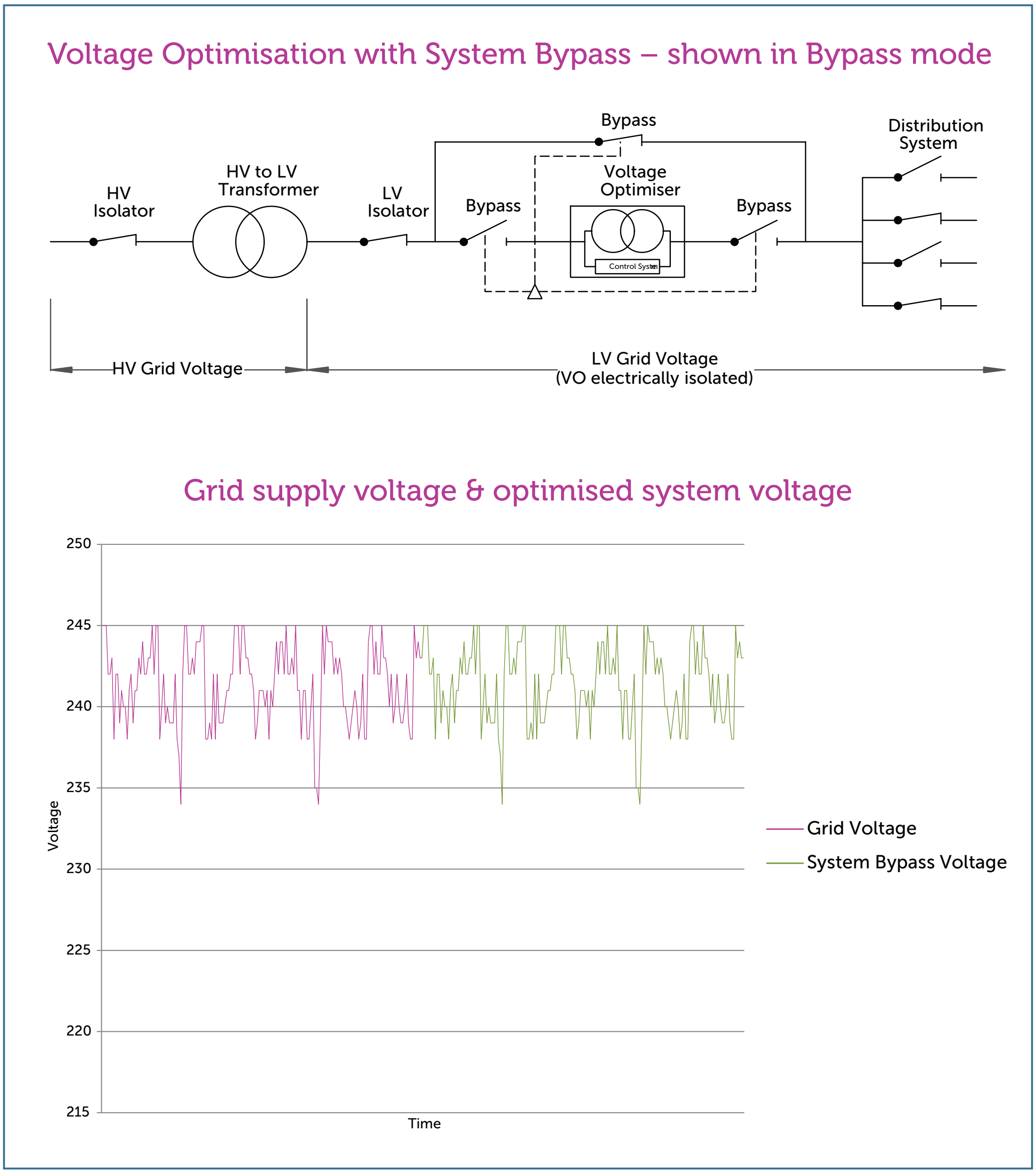


FIGURE 6: RESULT OF SYSTEM BYPASS

Metering system – an option for most Voltage Optimisation systems is to have an in built Metering, Monitoring & Testing (MM&T) system. The specifications of such systems may vary, but they can offer a useful base for a site that does not yet have any MM & T facilities. Generally a system will display real time information as well as giving access to historical data through an inbuilt data logging system. Various levels of access to the data are available from a basic local display to a web based dashboard type system. It is vital to understand the requirements for such a system and ensure that it is correctly specified to the Voltage Optimisation system manufacturer.

6
INSTALLATION AND SITE TESTING

Product installation must be undertaken by a suitably qualified competent person in line with the manufacturer's instructions and be in compliance with BS 7671:2008 +A3: 2015 and any other applicable local regulations.

Manufacturers of Voltage Optimisation equipment should provide an Installation, Operation and Maintenance Manual that should include the following detail as a minimum:

- Product description
- Product dimensions and weight
- Warning and safety guidance
- Mounting and location guidance
- Electrical connection guidance and when there is on site generation
- Guidance on environmental considerations, including airflow
- Product specifications, including details on Standards and Directives
- Commissioning guidance
- Operation of the Voltage Optimisation System
- Warranty information
- Servicing and routine maintenance guidance (where applicable)
- Technical support contact details
- Any consumables and spare parts required (if applicable)

For Domestic Properties, access to internal components shall be limited to trained and competent persons utilising the appropriate means of access or tool(s).

For Non-Domestic Properties, access to Voltage Optimisation Systems shall be limited to competent persons utilising the appropriate means of access or tool(s) only, to prevent access by unauthorised persons. Barriers and enclosures shall be provided as specified in BS EN 61439-1, Sections 8.4.6.2

NORMATIVE REFERENCES

The following referenced documents are indispensable for the application of this document. For dated references, the latest edition, including amendments, applies. For undated references, the latest edition of the referenced document including any amendments applies.

BS 7671:2008 + A3: 2015	Requirements for electrical installations. IET Wiring Regulations. Seventeenth edition.
BS EN 61439-1:2011	Low-voltage switchgear and Controlgear assemblies.
BS EN 61439-2:2011	Low-voltage switchgear and Controlgear assemblies.
BS EN 61439-3:2011	Low-voltage switchgear and Controlgear assemblies. Distribution Boards intended to be operated by ordinary persons (DBO).
BS EN 60076-11:2004	Power transformers. Dry-type transformers.
EN 60730-1:2000	Automatic electrical controls for household and similar use.
EN 61000-6-1:2007	Electromagnetic compatibility (EMC). Generic standards. Immunity for residential, commercial and light-industrial environments.
EN 61000-6-2:2007	Electromagnetic compatibility (EMC). Generic standards. Immunity for industrial environments.
European Community Directive 2006/95/EC	The harmonisation of the laws of Member States relating to electrical equipment designed for use within certain voltage limits or local equivalent.
European Community Directive 2002/96/EC	Waste electrical and electronic equipment (WEEE) or local equivalent.
BS EN ISO 9001:2008	Quality management systems.
BS EN ISO 14001:2004	Environmental management systems.

Westminster Tower
3 Albert Embankment
London SE1 7SL

www.beama.org.uk