MINISTRY OF DEFENCE

Property Directorate

DEFENCE ESTATES
Delivering Estate Solutions to Defence Needs

JUSTIFYING AND DELIVERING VOLTAGE OPTIMISATION ON THE MOD ESTATE

Practitioner Guide 01/10

Estate Management

Document Aim:

This Practitioner Guide (PG) is primarily intended for Ministry of Defence (MOD) Energy Managers in the UK who are interested in Voltage Optimisation as a means of reducing electrical energy consumption on their sites. It should also prove useful for those involved in managing electrical infrastructure on MOD establishments, such as Maintenance Management Organisations, Authorising Engineers, Infrastructure/M&E Utilities Managers and Site Estate Authority Teams.

Document Synopsis:

This PG provides procedural and some technical guidance on justifying and delivering Voltage Optimisation (VO) on the MOD estate. The target audience is the MOD Energy Managers who are showing increasing interest in this technology due to the overt marketing of VO equipment in the UK. As existing site conditions and the nature of connected load ultimately determine the effectiveness of VO as an energy reduction technique it may well prove that other cheaper and already proven options are more beneficial. These alternatives are also briefly discussed in this guide.

The document does not purport to support, or discredit, the installation of VO equipment but seeks to inform site managers on the various factors that need to be taken into account when considering the installation of such equipment.

Details of known VO equipment manufacturers/suppliers are provided to assist site managers in the selection of suitable contractors in accordance with normal MOD procurement methods.

The "Practitioner" to whom this Guide relates is MOD Energy Managers and other individuals or organisations who either have responsibility for energy management or are involved in the planning, design, installation and maintenance of electrical equipment on the MOD estate.

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Related Documents

JSP 375 MOD H&S Handbook Volume 3	PG 03/09 Low Voltage Installations
JSP 418 MOD Sustainable Development and Environment Manual	PG 04/09 Inspection & Testing
DE Specification 034 Electrical Installations	

Contents

Annexes:

Abbreviations

A	Amperes
AE	Authorising Engineer
BS 7671	BS7671:2008 Requirements for Electrical Installations (IEE Wiring Regulations)
CDM	Construction (Design and Management) Regulations 2007
CVR	Conservation Voltage Reduction
DE	Defence Estates
CFL	Compact Fluorescent Lamp
DNO	Distribution Network Operator
EAWR	Electricity at Work Regulations 1989
ESQCR	Electricity Safety, Quality and Continuity Regulations 2002
GLS	General Lighting Scheme
HSE	Health and Safety Executive
HVAC	Heating Ventilation and Air-conditioning
IEC	International Electrotechnical Commission
JSP	Joint Service Publication
kW	Kilowatt
kWhr	Kilo-Watt-hour
kVA	Kilo-Volt-Amperes
LV	Low Voltage
M&E	Mechanical & Electrical
MMO	Maintenance Management Organisation
MOD	Ministry of Defence
OEM	Original equipment Manufacturer
PG	Practitioner Guide
P&TS	Professional & Technical Services
PME	Protective Multiple Earthing
RCD	Residual Current Device
SMPS	Switched-mode Power Supplies
SRP	MOD Safety Rules and Procedures (JSP 375 Volume 3)
UPS	Uninterruptible Power Supply
V	Volts
VFM	Value for Money
VO	Voltage Optimisation
VSD	Variable Speed Drive
W	Watts

1.0 INTRODUCTION

Electricity is the most expensive form of energy available - about eight times the cost of coal and six times the cost of gas - this expensive fuel must be used wisely! CDA, 1997[1]

1.1 Reducing energy consumption not only saves money but enhances MOD's reputation and assists in the fight against climate change by reducing carbon emissions. As part of overall electrical energy-reduction strategy there is considerable interest amongst MOD Energy Managers to install voltage reduction devices as a quick-win solution.

1.2 The principle of selecting the most appropriate operating voltage for the equipment is known as voltage optimisation (VO). It is not simply reducing the voltage, although in the UK it does normally involve reduction. VO is also known as voltage power optimisation, voltage reduction, conservation voltage regulation/reduction or voltage correction. The aim of VO is to reduce energy consumption while maintaining performance of equipment.

1.3 Although the concept is not new the overt marketing of voltage optimisation technology in the UK is fairly recent, as is the increased interest within the MOD. While this technology appears attractive, site conditions and the type of connected load may, in some instances, prove that other cheaper and more well-established options are more beneficial. Such alternatives are briefly discussed in this guide.

1.4 While it is widely accepted that some linear loads, mainly lighting, will benefit from VO it is not uncommon for manufacturers[2] of voltage reducing or "energy limiting" equipment, hereinafter referred to as voltage optimisation devices, to claim that their equipment raises system efficiency with resultant reduction in energy consumption by as much as 22% or more. Within the electrical engineering profession opinions are divided on the benefits of voltage reduction. There is also a degree of scepticism on the amount of claimed savings achievable. This scepticism exists primarily because of competing manufacturers' efficiency claims and limited third party evaluation.

1.5 Details of known VO equipment manufacturers/suppliers are provided to assist site managers in the selection of suitable contractors in accordance with normal MOD procurement methods.

2.0 AIM

2.1 This PG is primarily intended for MOD Energy Managers in the UK who are interested in VO as a means of reducing electrical energy consumption on their sites. It should also prove useful for those involved in managing electrical infrastructure on MOD establishments, such as Maintenance Management Organisations[3] (MMOs), Authorising Engineers, Infrastructure and/or M&E Utilities Managers and Site Estate Authority Teams.

2.2 The PG does not purport to support, or discredit, the installation of VO devices but seeks to inform site managers on the various factors that need to be taken into account when considering the installation of such equipment.

[1] Copper Development Association, Electrical Design, A Good Practice Guide, CDA Publication 123, 1997.
[2] In this document a manufacturer refers to a manufacturer, supplier or authorised installer of specialist equipment e.g. voltage optimisation device
[3] The generic term MMO has been used to represent the contractor providing maintenance services under all delivery methods, e.g. PPP / PFI / RPC / MAC/Stand Alone Prime.

3.0 SUSTAINABILITY

When considering the installation of a VO device its sustainability criteria should meet that of JSP 418[4]. Further information is at Annex A.

4.0 TECHNICAL CONSIDERATIONS

4.1 The installation of VO devices requires thorough consideration of various technical factors. Further details, including the simple explanation of VO principle and types of VO devices available on the market, are at Annex B.

4.2 Main VO devices are normally installed at the supply intake point of a building. They are fitted between the main intake switch/breaker and the main distribution board. VO devices are of dry construction and do not contain oil, so there is little restriction on their installation indoors. However, early confirmation is required on the availability of adequate floor space and that the floor can withstand the additional load imposed by the equipment as the provision of suitable weatherproof housing and extra cabling will add to the overall cost. Some main devices can also be fitted between the site transformer and feeder pillar but this requires some modification to the existing cabling and equipment. VO devices for lighting, which are much smaller and lighter, are usually installed adjacent to the lighting distribution board.

5.0 ROLE OF AUTHORISING ENGINEER

5.1 The Authorising Engineer (AE) is the technical authority who must, with the exception of the small devices for lighting loads and individual motors, approve the installation of any VO device on the MOD estate. The AE’s role is primarily to ensure that safety requirements are met with respect to the proposed installation and the existing installation is not adversely affected by the addition of the VO device. For this reason the MMO must ensure the AE is involved in the technical appraisal from the very start.

5.2 It is not the AE’s responsibility to confirm that energy savings are achievable or to deny the installation of the VO device based on the premise that energy savings may not be achievable. Further details are at Annex C.

6.0 STATUTORY REQUIREMENTS

The introduction of the VO device into an existing installation must not adversely affect the safety and operation of the existing installation. Pre-installation and post installation checks must be conducted to ensure that the requirements of the Electricity at Work Regulations 1989 (as amended) and Electricity Safety, Quality and Continuity Regulations 2002 (as amended) are met. Further information is at Annex D.

7.0 FUTURE CHANGES TO THE ESTATE

7.1 The effect of VO device on the site’s currently connected electrical load as well as make up of the future load must be also considered. Furthermore, as new buildings are required to be designed to meet the energy efficiency criteria specified in Building Regulations Part L the benefit from the VO device may diminish significantly with the new installation.

7.2 This is also true when buildings are refurbished because once again they must be

[4] Ministry of Defence Sustainable Development and Environment Manual

brought up to Building Regulations standard. Furthermore, if removal or replacement of the VO equipment is found to be necessary there will be additional associated costs which need to be factored in.

7.3 Where available the site's Integrated Estate Management Plan, which will highlight the proposed future changes to the estate, should be consulted during the planning stage.

8.0 INITIAL LOAD SURVEY

8.1 The nature of the connected load determines if any significant energy savings can be achieved through VO. It is therefore crucial that, prior to arriving at a decision to install any VO device, an independent survey of the facilities electrical energy consuming equipment is undertaken. The purpose of the initial load survey is to:

- Determine whether VO is a viable option for energy reduction.
- Identify potential opportunities for energy savings through VO.
- Identify loads which may suffer as a result of VO, and if they exist, can these be replaced, modified or adjusted to render them suitable and beneficial for use with VO.

The independent initial load survey should be arranged through the MMO. Survey undertaken by the manufacturer is not to be accepted as independent.

8.2 Where any doubt exists as to equipment's suitability for operation at a lower voltage, advice from the original equipment manufacture (OEM) must be sought, as some warranties may become void due to the adverse effect of VO. In particular, care should be taken with older equipment with nominal rating of 240V.

8.3 The survey will be conducted as part of the survey required to fulfil the requirements of the sustainability considerations detailed at Annex A. If the initial load survey confirms the suitability of VO as a means of reducing energy consumption a Pre-installation Energy Survey is to be undertaken as detailed at Paragraph 12.1.

8.4 Depending on existing contracts there may be costs associated with carrying out the initial survey. Where required the funding will have to be found by the Energy Manager and agreed with the MMO through existing arrangements. The cost of the initial survey may be negotiated together with the cost of the post installation survey where this is clearly more beneficial to the MOD, with the caveat that the latter may not be required if VO is not an option for the site.

9.0 EFFECT OF VOLTAGE OPTIMISATION ON CONNECTED LOADS

Table 1 below gives indication of the effects of VO on commonly encountered loads. For other loads of specialist nature the OEM must be consulted. This table should be referred to during the initial load survey.

Electrical Load Type	Effect of Voltage Reduction	Remarks
Lighting – Domestic	General Lighting Scheme (GLS) incandescent lamps – energy saving achievable	Life of the lamp will increase with reduced voltage. Tungsten filament lamps also offer savings but at the cost of reduced illumination level. GLS – being phased out by 2011
Lighting – Domestic	Compact Fluorescent Lamps (CFL) – No energy saved as	Lamp may fail to operate at excessive reduced voltage unless dimmable type

Electrical Load Type	Effect of Voltage Reduction	Remarks
	these are constant power lamps	
Lighting - Commercial	HF Electronic ballasts - No energy saved. Equipment operate satisfactorily within operating range	CIBSE document, Fact File No 5 August 1997, Advice regarding High Frequency (HF) electronic luminaires, advises that voltage optimisation is not compatible with HF lighting
Lighting - Commercial	Magnetic ballasts – high savings achieved	Fluorescent luminaires with magnetic ballasts offer the greatest savings. VO is a good option than replacing magnetic ballasts/luminaires with more efficient type
Lighting – industrial type	Energy saving achievable. Operates satisfactorily within operating range	High Pressure Sodium (SON, SONT), High Pressure Mercury (MBF) & High bay installation
Lighting – Street Lighting[5]	Energy savings achievable. Operates satisfactorily within operating range	Primarily low pressure sodium (SOX) lamps. Power factor also improves with voltage reduction
Motors – Linear (fixed) speed	Only where the motor is oversized and lightly loaded may VO achieve energy saving	A comparatively modest fall in the voltage will result in a much larger reduction in torque capability, causing overheating and decreased life expectancy of the motor. Standard squirrel cage induction motor torque output is proportional to the voltage squared. Therefore a 10% reduction in terminal voltage will result in a torque reduction of 19% (1 - (0.9 x 0.9)), it is therefore important that for standard induction motors the actual motor load is verified and the continued suitability of the motor post installation of any VO device is verified
Motors – Linear (fixed) speed		
Motors – Variable Speed Drives (VSD)	No energy savings achieved - constant power device	Operate satisfactorily within operating voltage range but the current drawn increases proportionally with reduced voltage. The suitability of the supply conductors and control equipment for any increase in current resulting from the reduced voltage must be checked
Motors – Other drives	Refer to original equipment manufacturer	For all other electric drives their suitability for operation at the reduced voltage must be confirmed with the equipment manufacturer. The supply current may increase correspondingly with voltage reduction therefore suitability of the supply conductors and control equipment must be checked
HVAC Installations	Energy saving may be achieved if equipment is oversized. As for linear motors	Heating pumps, ventilation and air-conditioning systems may offer some opportunities for energy savings where driven by non-optimised induction motors but **variable speed drives** are always the preferred option for maximising return on investment (ROI)

5 Electricity Association Load Research Group Street Lighting Research Project May 2002 (35 Watt Low Pressure Sodium lamps (35W SOX) fitted with Low Loss Control Gear.

Electrical Load Type	Effect of Voltage Reduction	Remarks
Kettle/boiler - thermostatically controlled resistive load	No energy saving achieved	Life of the heater element will increase with reduced voltage, but no energy saving will be obtained, as the heater element will still need to consume the same amount of energy to perform its required function. Although the power supplied to the heater element will reduce it will remain in the "on" position for much longer consuming the same amount of energy
Space Heating – thermostatically controlled resistive load	No energy saving achieved	Temperature-controlled heating is another type of load where no energy saving will be obtained, as the heater will still need to consume the same amount of energy to perform its required function. Although the power supplied to the heater will reduce it will remain in the "on" position for much longer consuming the same amount of energy
Embedded LV generation /Uninterruptible Power Supplies	May require resetting of protective relays to ensure that these operate at reduced voltage as designed without detrimental effect	
IT equipment (switched mode power supply)	Constant power device. No energy saving achieved. Operates satisfactorily within operating range but consumes same power	Where a significant proportion (30% or more) of the site or facility electrical load is made up of electronic devices containing switch mode power supplies (SMPS), information systems equipment in particular, the supplying circuits' suitability for any potential increase in current due to the reduced voltage must be verified. Because SMPS supply constant power there is corresponding increase in the current taken by the equipment as the voltage is reduced. In order to maintain constant power input the equipment draws more current to compensate for the reduced supply voltage. The summation of all the increased currents from individual equipment could potentially overheat distribution boards running at or near capacity. The protective devices may also trip spuriously
Lifts	Possible problems	Lift manufacturer must be consulted

Table 1: Load Types and Effect of Voltage Optimisation.

10.0 VALUE FOR MONEY

10.1 Simple Payback Period

An energy investment's Simple Payback Period is the amount of time it will take to recover the initial investment in energy savings. This is calculated by dividing the initial outlay by the annual energy cost savings. For example, an energy-saving measure that costs £5,000 and saves £2,500 per annum has a Simple Payback Period of:

$$\frac{£5000}{£2500} \text{ or 2 years}$$

While Simple Payback is easy to compute and useful for making rough estimates of how long it will take to "recoup" an initial investment, its weakness is that it fails to factor in the following:

- time value of money
- inflation
- project lifetime or operation
- maintenance costs

10.2 Whole Lifecycle Cost Consideration

To take these factors into account, a more detailed Lifecycle Cost Analysis must be performed. The MMO is expected to consider whole lifecycle costs when determining the value for money case. Proposed changes to the estate as well as the replacement of existing electrical equipment by more efficient type in the future will have a bearing on the analysis.

11.0 BUSINESS CASE

11.1 A business case to install VO equipment is only to be raised if the initial load survey concludes that:

- No connected load would suffer as a result of VO, or that replacement of the affected equipment will be advantageous.
- VO is a viable option for energy reduction.
- There are opportunities for energy savings to be achieved immediately through VO.

11.2 As previously mentioned investment in energy efficiency should generally be recouped within a reasonably short period - say 5 years or so. Initiatives with initial investment having a simple payback of greater than 5 years may be given a lower priority although this should not prevent a funding request being put forward. The Energy Manager will be expected to submit a robust business case for funding approval. A suggested Checklist for the use of the Energy Manager to support the business case is at Annex E. Much of the information required to populate the Checklist should be obtained from the MMO. The Checklist can also be used post funding approval right up until the work is fully completed.

11.3 In most cases it is anticipated that the proposed VO device installation will have to be programmed in as Minor New Works into the following year’s programme. This will mean the funding for the proposed works will have to be secured in advance in accordance with locally established procedures.

12.0 PRE-INSTALLATION WORK

12.1 Once funding has been secured and the contract for the procurement of the VO equipment has been awarded there remains the following important works which need to be completed prior to the installation of the VO device:

- Pre-installation Energy Survey.
- Confirmation of earth loop impedance values.

12.2 Pre-Installation Energy Survey

12.2.1 Prior to the installation of the VO device an independent survey of the facility's energy consumption, power factor and power quality should be made for a representative period of not less than one month. The survey is to be arranged through the MMO. Surveys undertaken by the equipment supplier or their nominated representative is not to be regarded as independent.

12.2.2 The survey results are necessary if reasonable comparisons are to be made of the energy usage and establish a benchmark on which the manufacturer's cost/benefit proposal is based, as well as relevant data other system characteristics, prior to and after the installation of the VO device. For this reason this survey is to be undertaken as near as possible to the time of the installation of the VO device.

12.3 Confirmation of Earth Loop Impedance Values

12.3.1 Prior to the installation of the VO device the existing earth loop impedance readings for the circuits protected by the lowest and the highest rated protective devices on the down-stream distribution boards of the proposed VO device should be determined through the MMO. These tests are to be made as near as possible to the time of the installation of the VO device. These impedance values should be compared with impedance values obtained for the same circuits following installation of the VO device. These newly measured values should be checked to confirm the operation of the protective devices have not in anyway been compromised.

12.3.2 Annex D (Paragraphs 3.0-3.3) provides further information.

13.0 INSTALLATION OF THE VO DEVICE

13.1 The actual installation work will have to be planned, coordinated and undertaken with little or no disruption to the normal operation of the site.

13.2 It is recommended that the installation of the VO device is undertaken by the contractor (manufacturer/supplier) using its own supply chain. This would place the risk on the contractor and not the MOD. Where coordination is required with the Distribution Network Operator (DNO) for isolation of the supply it is the contractor's responsibility to arrange this through the MMO. This co-ordination would normally be required where the site receives an LV supply direct from the DNO. Normal security clearance will be required for the contractor's staff to enter the MOD site to undertake the works. The contractor must factor this into their programme.

14.0 HANDOVER PROCEDURES

14.1 On completion the contractor is to handover the newly completed part of the works to the MMO. Electrical Installation Certificate containing the full test results and As-built drawings shall be handed over to the MMO.

14.2 Zs values shall be measured by the contractor for the circuits protected by the lowest and the highest rated protective devices on the down-stream distribution boards to confirm that their performance have not been compromised.

15.0 POST INSTALLATION SURVEYS

15.1 Subsequent to any installation of a VO device an independent verification of the device's performance must be sought. This independent verification should be arranged through the MMO. The purpose of this verification survey is two-fold:

- Check of all power consuming equipment to ensure they are operating without detriment at the reduced voltage.

- Verification of all performance claims made for the VO device.

15.2 During the verification period no changes to the facility's electrical installation should take place that might bring into question the validity of the verification. Additionally, other active energy conservation measures should not be introduced during the verification period for the same reason.

16.0 MANUFACTURERS GUARANTEE

Some manufacturers of VO equipment provide guarantee on their claimed savings. This guarantee should be sought at the tender stage from all bidders. If, subsequent to the VO device installation, it is found that the manufacturer's claims are false and the benefits are insignificant, option should be available for removal of the equipment by the supplier at nil-cost and the MOD fully reimbursed.

17.0 PROCESS CHART FOR VO DEVICE PROCUREMENT

With the exception of minor works associated with task specific VO requirements such as lighting circuits, the procurement of the VO equipment can be divided into two phases. These will require separate funding approval as the final outcome of the preliminary study report, including the initial connected load survey, will dictate if the proposal can proceed any further.

17.1 Phase 1 – Investigation Stage.

During this phase the Energy Manager has to determine whether VO is an option for his/her site. The Energy Manager has to obtain this information from the MMO (and not through a VO equipment supplier/manufacturer), which in itself may have cost implications. Hence, funding may have to be secured for the first phase of the works before requesting the MMO to produce a preliminary study report to include:

- Suitability of the connected load for VO.
- Immediate realisation of energy savings with VO.
- Simple payback period calculation and value for money assessment to include whole lifecycle costs for the scheme.
- Rough order of costs for the installation of the VO equipment, including any associated work to be carried out by the MMO, such as the pre and post installation surveys.

The report can be used to support the business case for the phase 2 works.

17.2 Phase 2 – Procurement Stage.

Once funding is secured the Energy Manager is required to programme-in the works with the MMO. On completion of the works the Energy Manager should ensure that the performance of the VO equipment compares favourably with the claims made by the supplier/manufacturer of the VO device. Although this will have to be done through the MMO the responsibility lies with the Energy Manager to follow through the procurement process to full completion.

The Process Chart shown in Figure 1 should be followed when considering VO as a means of reducing electrical energy consumption on site. This Process Chart should be used in conjunction with the Checklist at Annex E.

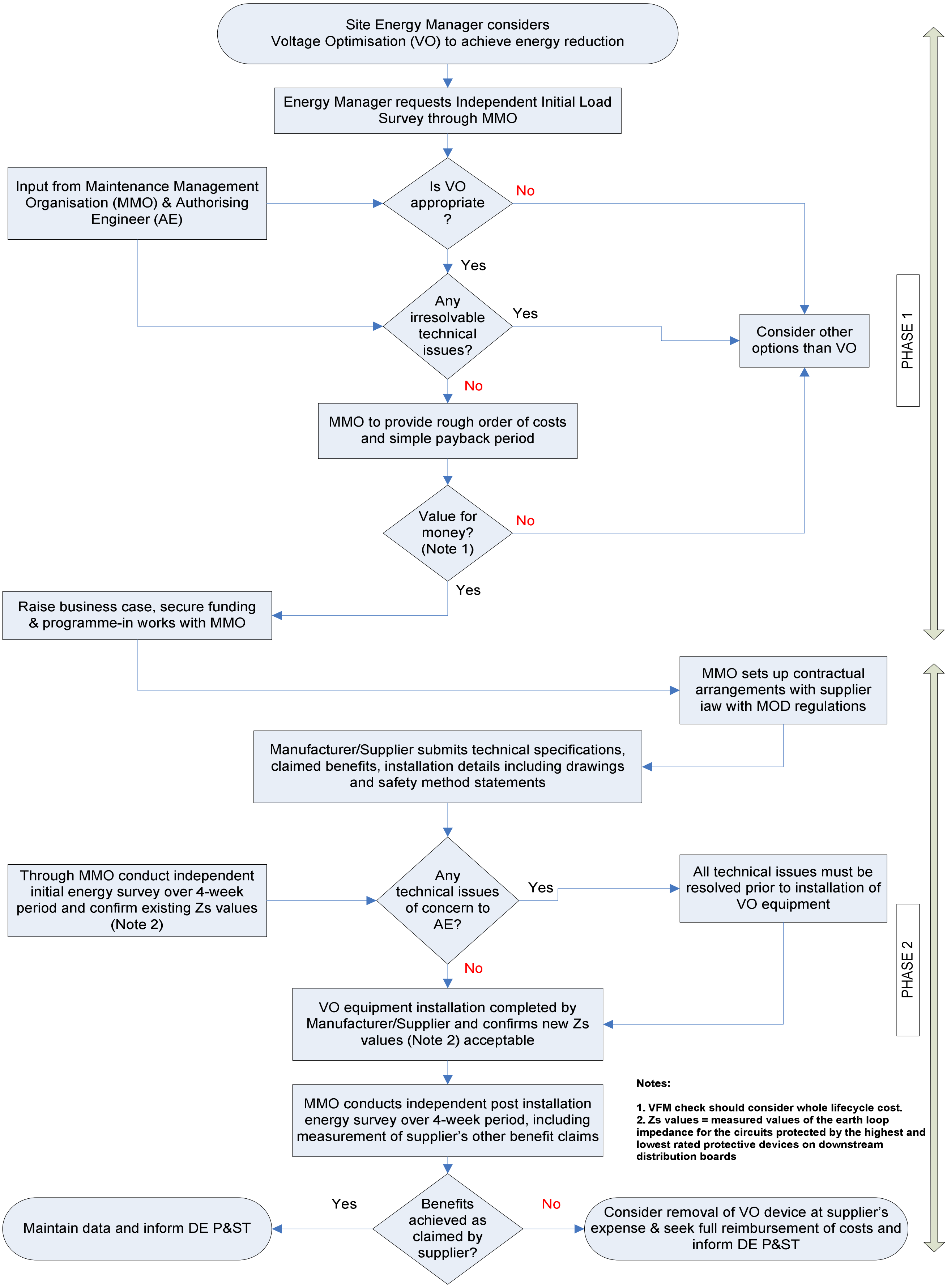

Figure 1: Voltage Optimisation Process Chart

18.0 ALTERNATIVES TO VOLTAGE OPTIMISATION

18.1 Introduction

With the exception of the smaller units designed for lighting circuits and individual motors, installation of VO devices require significant capital outlay. The purpose of this section is to briefly mention other initiatives that may prove to be more beneficial in conserving electrical energy than investing in VO device(s). In particular, the selection of an alternative method may be the only solution if, following the initial load survey, it becomes apparent that VO is not an option.

18.2 Background

Energy Managers will be familiar with well-established energy saving measures that can be applied across their sites. Best practice guidance is also widely available; hence, this section will be kept brief. It is recognised that on an existing site the decision to employ energy efficient equipment is primarily the responsibility of the MMO but it is hoped that their mention here raises awareness in Energy Managers.

18.3 Conduct an (Electrical) Energy Survey

Engage an independent industry expert, through the MMO, if the MMO cannot undertake this. Energy survey undertaken by the VO device manufacturer should not be accepted as independent. This will apprise you of the provision and utilisation efficiency of electrical energy sources within a building/process or the whole site, together with identification of energy waste. The report will include recommendations on energy saving opportunities, suitably evaluated. It will also include financial appraisal on estimated equipment costs, energy savings, and simple payback for each recommended item.

18.4 Use of Energy Efficient Equipment

When old electrical equipment is due for replacement ensure the new equipment is of the most energy efficient type. This responsibility normally falls on the MMO. Although the initial outlay for the energy efficient equipment could be considerably more than for a standard type the cost is usually recouped through energy savings within a few years. During major refurbishment works there will be opportunities to replace inefficient luminaires with efficient ones, for example replacing T12 and perhaps T8 lighting with T5 type. Any opportunity should be exploited to the full. The installation of energy efficient transformers, motors, lamps and luminaires, as well as motor drive systems, should also be considered. It may also be economically beneficial to replace inefficient equipment well before the end of its operational life but this should only be executed if it is fully supported by an investment appraisal.

18.5 Use Variable Speed Drives (VSD)

When opportunities arise consider replacing the standard motor drive system (motor driven pumps/fans/refrigeration plant/compressors employing conventional throttle/damper controls) with VSD and high efficiency motor. The simple payback period is usually between 2-4 years. Use of VSD can be particularly beneficial with variable loads, such as in heating, ventilation and air-conditioning systems.

18.6 Transformer Tap Adjustment

If the LV supply is on the higher end of the statutory limit consider resetting the transformer tapping to adjust the site voltage down to 230 V, if there is no detrimental effect on the connected load. This can be done at minimum cost and disruption and could save up to 5% in energy consumption depending on the connected load type. Voltage drops at the furthest points of the installation must be checked to ensure that equipment is not adversely affected by this adjustment.

18.7 **Lighting Control**

Good lighting control design and the use of occupancy sensors ensure that use of lighting is optimised and turned off when the room/building is not occupied. This approach can save 20-40% in lighting energy usage. Remember that GLS lamps are being phased out by 2011.

18.8 **Metering**

Strategically placed electricity meters provide energy consumption data for energy monitoring and targeting (M&T). The process of M&T allows regular comparisons of actual energy use against planned or budgeted data, to identify if problems are becoming apparent. There is an MOD initiative already in place under "Smart Metering Programme" to install additional meters. Make intelligent use of them.

18.9 **Power Factor**

Consider installing power factor correction equipment if your site's power factor is poor, e.g. <0.96. This will not only reduce system losses but also help to reduce the kVA maximum demand and reduce electricity bills. These vary in size and can be installed at a substation feeding a low power factor load, or at main intake into a building, or even adjacent to an equipment with a poor power factor.

18.10 **Harmonic Filters**

Consider installing harmonic filters to improve power quality and system energy losses upstream of the filter, i.e. in transformer and supply cables. Harmonics can be of particular issue where non-linear loads are in prominence. Harmonic currents overload neutrals, overheat transformers, erroneously trip circuit breakers and overstress power factor correction equipment. Harmonic voltages on the other hand distort the voltage, introduce "noise" and overheat induction motors.

19.0 **MANUFACTURERS OF VO EQUIPMENT**

Table 2, which is not exhaustive, lists the UK Manufacturers/Suppliers of VO devices/equipment. BMASS Energy Saving Solutions Pty Ltd is an Australian manufacturer.

Manufacturer/ Supplier	Contact Details	Products
Claude Lyons Limited	Brook Road Waltham Cross Herts, EN8 7LR Tel: 01992 768888 Fax: 01992 788000 Email: info@claudelyons.co.uk Web: http://www.claudelyons.co.uk/energy.htm	Voltage reducing transformers – 1ph or 3 phase transformers up to 2,160 kVA. AC Voltage stabilisers – active type employing motor-driven variable transformer. Range from 5.5 kVA to 1,104 kVA Energy Saving Voltage Regulators 23 kVA to 1,440 kVA
Energy Management Systems	EMS House 7 Genesis Park Sheffield Road, Rotherham S60 1 DX Tel: +44 (0)1709 836200 Fax: +'44 (0)1709821276 Email: info@ems-uk.org Web: www.ems-uk.org	PowerStar Fixed – passive Voltage Optimiser PowerStar Servo – solid state active Voltage Optimiser From 30 kVA to 3,000 kVA units

Manufacturer/ Supplier	Contact Details	Products
PowerPerfector	1-10 Praed Mews London, W2 1QY Tel: 0845 601 4723 Fax: 0845 601 4724 Email: info@powerPerfector.com www.powerPerfector.com	PowerPerfector –passive Voltage Optimiser for power installations PowerPerfector Plus – solid state active Voltage Optimiser for power installations All optimisers are 3 phase only. Available in sizes ranging from 30 KVA to 3,000 kVA
Schneider Electric Limited	(North West Customer Support Centre) Schneider Electric Ltd, First Floor, Market House, Church Street, Wilmslow Cheshire SK9 1AY Tel: 0870 608 8 608 Web: http://www.schneider-electric.co.uk/internet/pws/webqueries.nsf/formWebContact?open	Lubio Lighting Controllers – suitable for retrofitting on large loads that are switched on for long periods of time e.g. car parks and warehouses
SDC Industries Ltd	18 Colvilles Place Kelvin Industrial Estate East Kilbride, Glasgow, Lanarkshire, G75 0PZ Tel: +44 (0)1355 265959 Fax: +44 (0)1355 265484 Email: info@sdcindustries.co.uk Web: http://www.sdcindustries.com/index.html	Varmatic VoltageMaster - Voltage Optimiser for power installations Varmatic LightMaster – Voltage Optimiser for lighting installations The optimiser is available in sizes ranging from 30 KVA to 2,000 kVA Also Power Factor Correction and Harmonic Filters – range of products
BMASS Energy Saving Solutions Pty Ltd	David Nickols, Director BMASS ENERGY SAVING SOLUTIONS PTY LTD PO Box 5981, Stafford Heights, QLD 4053, **Australia** Tel: +61 7 3206 9668 Fax: +61 7 3829 3821 Mob: +61 418 382 911 email: david@bmass.com.au Web: http://www.bmass.com.au/index.htm	BMASS Power Saver - Voltage Optimiser for fluorescent lighting and High Intensity Discharge (HID) / High Bay Lighting such as sodium, mercury and metal halide

Manufacturer/ Supplier	Contact Details	Remarks
Fluoresave Limited	Kintbury Holt Farm Kintbury, Newbury, Berkshire, RG20 0DD Tel: +44 (0)1488 658480 Fax: +44 (0)1488 657212 Email: info@fluoresave.com Web: www.fluoresave.com	Fluoresave - Voltage Optimiser for fluorescent lighting and High Intensity Discharge (HID) / High Bay Lighting such as sodium, mercury and metal halide
SavEnergi Ltd	PO Box 320 Stevenage, SG2 8WT Tel: 0845 330 8864 Fax: 0845 330 8865 Email: info@SavEnergi.com Web: http://www.savenergi.com/index.shtml	Energy saving control devices - Voltage Optimiser for fluorescent lighting and High Intensity Discharge (HID) / High Bay Lighting such as sodium, mercury and metal halide
Watford Control Instruments Limited	Godwin Road Corby Northamptonshire NN17 4DS United Kingdom Tel: +44 (0)1536 401345 Fax: +44 (0)1536 401164 Email: sales@watfordcontrol.co.uk	Powersaver AC Voltage Energy Saving Regulators ratings up to 4,000 kVA

Table 2: Manufacturers/Suppliers of VO Equipment.

ANNEX A – SUSTAINABILITY

JSP 418

1.0 To accord with the requirements of JSP 418[6] the life-cycle costs of available alternative technologies must be reviewed against the life-cycle cost of the VO device and its installation. This requirement is also stipulated in the Office of Government Commerce (OGC) Guidance: Energy Efficiency in Procurement[7]…. "Value for money has been defined as 'the best mix of quality and effectiveness for the least outlay' *on a whole life basis*".

1.1 Therefore, the installation and operating costs of such items as high frequency lighting, using tri-phosphor lamps, replacing T12 and T8 fittings with T5 fittings, retro-fitting of compact fluorescent lamps into existing luminaires, installing variable speed drives for motors and similar energy saving technology must be taken into consideration along with a comparison of the environmental benefits.

1.2 The above must take into account the age of the installation and the likelihood of near-term refurbishment of the facility, where the requirements of the Building Regulations may require the installation of energy saving lighting and other energy efficient equipment, as such actions will reduce the amount of savings realised from the investment of the VO device in the first place, or even negate it entirely.

Further Guidance

2.0 For lighting installations the guidance in the Lighting Industry Federation Technical Statement No. 3 must be followed. This is available at http://www.lif.co.uk along with other authoritative publications relating to lighting. Voltage reduction must not have serious affect on the designed illumination levels in the push to conserve energy.

2.1 Further guidance on sustainability in energy can also be found at the EU sponsored Leonardo Energy Global Community for Sustainable Energy Professionals at http://www.leonardo-energy.org

[6] Ministry of Defence Sustainable Development and Environment Manual
[7] OGC Considering Energy Efficiency in Procurement Guidance Notes

ANNEX B – TECHNICAL CONSIDERATIONS

UK Supply Voltage

1.0 Following European Union (EU) harmonisation in 1995, the variations in electricity supply voltage permitted by BS EN 50160 throughout Europe is 230 V +/-10% (i.e. 207-253 V)[8] for single phase and 400 V +/-10% for 3 phase. In the UK variation is currently limited to +10% -6%[9]. In some parts of the EU the variation is limited to +6% -10%. In reality this means that the actual voltages experienced in most of Europe remains the same. The common nominal voltage facilitates free movement of goods.

1.1 There have been no physical changes made to the UK supply voltage as a result of this regulation because the existing voltage range falls well within the new voltage band. In fact, on average it is accepted that UK supply is still about 242 V[10], while the EU average is 220 V.

Voltage Fluctuations

2.0 Where passive VO systems are being considered the local distribution network operator (DNO) must be consulted with respect to the voltage stability of the local network configuration and any foreseeable changes that may result in a reduction in source voltage. As well as the affect of network configuration changes source voltage may experience seasonal variations, for example reduced voltage during the height of summer months, which must be considered.

Effect of Supply Voltage on Electrical Equipment

3.0 Although electrical equipment is designed to operate safely within the normal margins of rated voltage, most operate most efficiently at the rated nominal voltage[11]. Equipment operating at outside the rated voltage band will be adversely affected and could also void original equipment manufacturer's warranties.

3.1 Since harmonisation, any electrical equipment manufactured for the EU market is designed to operate on mains supplies according to BS EN 50160:2007[12] i.e. at 230 V +/-10% or between 253 and 207 V. Equipment manufactured pre-1995 will invariably be designed for 240 V +/-6% and it must not be assumed that every item of equipment will operate more efficiently, or even satisfactorily, at reduced voltage of 230/220 V. Pre-1995 equipment will still be widely found throughout the MOD sites.

3.2 The voltage rating of equipment, however, is only one of several factors to be considered. It is important that other issues, such as the safety and operability of the electrical system as a whole and proposed future changes to the estate, are also taken into account.

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[8] Harmonisation Document HD 472 SI Nov 1988 incorporating Corrigendum Feb 2002: Nominal voltages for low voltage public electricity supply systems (includes amendment A1:1995).
[9] The Electricity Safety, Quality and Continuity Regulations 2002.
[10] Source: ELEXON Balancing and Settlement Code Company for Great Britain. http://www.elexon.co.uk
[11] Nominal voltage – voltage by which an installation (or part of an installation) is designated. The actual voltage of the installation may differ from the nominal value by a quantity within normal tolerances.
[12] BS EN 50160:2007: Voltage characteristics of electricity supplied by distribution networks.

Principle of Voltage Optimisation

4.0 The principle of selecting the most appropriate operating voltage for the equipment is known as voltage optimisation (VO). It is not simply reducing the voltage, although in the UK it does normally involve reduction. VO is also known as voltage power optimisation, voltage reduction, conservation voltage regulation/reduction or voltage correction. The aim of VO is to reduce energy consumption while maintaining performance of equipment.

4.1 In some linear loads, such as incandescent lamps and equipment with resistive heating elements, if the supply voltage is higher than its rated nominal voltage the equipment draws more power. The increased power results in higher energy losses to occur not only in the equipment itself, but also in the distribution transformer and all downstream cables supplying the item. In the case of motors over voltage will lead to increased energy losses in the form of copper and friction losses. Over voltage also puts extra stress on the insulation leading to diminished equipment life. However, in other non-linear loads such as computers, modern lighting controllers, electric welding machines and variable speed driven motors, the power supplied is not affected by voltage variations.

4.2 Voltage reduction can be crudely achieved by changing the manual tap setting on the transformer at a minimum cost. However, a VO device allows this to be achieved much more accurately because it has more tapings available to provide finer ranges of voltage output. In the case of an active VO device the output voltage can be maintained at a value within a narrow band irrespective of the deviations in the supply (input) voltage.

4.3 Where some task specific VO device is already in use the installation of a second VO device in tandem is not recommended as any benefit from installing the second (main) VO device is negated to some extent. If the installation of the main VO device is justified the task specific ones may have to be removed prior to its installation.

Types of Voltage Optimisation Devices

5.0 VO devices are available in two forms: a passive type, in which the load side voltage moves up and down in sympathy with the input voltage, and an active type, whereby the load side voltage is maintained at a constant value within given limits irrespective of the input voltage. The initial capital cost of the active type is significantly more (>30-40%). Some active devices are solid state type without moving parts but some have electro-mechanical parts that require more maintenance than the passive type. VO devices also come in the form of smaller units that can be used to control the supply voltage to individual distribution boards supplying groups of lighting circuits.

5.1 Regardless of what the VO device is called, or whatever shape or form it takes, in the UK the device is used to reduce the voltage supplied to the installation/load.

5.2 Some VO device suppliers claim that their equipment reduces harmonics, improve power factor and improve phase voltage imbalance, which all contribute to reducing energy losses and enhance system efficiency. However, these claims have not been independently verified. If these claims are true, the additional benefits cannot be fully realised by simple adjustment of the transformer tap setting to reduce the site supply voltage. Some manufacturers also claim that their device protects the installation against voltage surges or transients by acting as in-line reactors.

5.3 Whatever type of VO device is selected it must be manufactured to a known standard and CE marked. For example, for a transformer type this may be to BS EN 600726-11:2004 Power Transformers: Dry Type Transformers or to BS171 – IEC 60076 – IEC 60726.

5.4 It is worth considering the installation of task specific VO devices, for example dedicated to a lighting installation, as a more pragmatic and simpler way of delivering a similar goal, but with less complexity and compatibility issues.

By-pass Device

6.0 Some VO devices have integral bypass facility fitted as standard, on others it has to be specified. No VO device shall be installed without a by-pass device except where the installation is on a final sub-circuit or group thereof, i.e. installation on the lighting distribution circuits of a high bay installation. This is to ensure that the VO equipment can be isolated and the installation reinstated to its former configuration following one or more of the following reasons:

- VO device proves to be unbeneficial
- VO device develops a fault
- Other connected equipment fails to operate satisfactorily.

Conservation Voltage Reduction Factor

7.0 As mentioned above the type of connected load has a direct bearing on whether any meaningful amount of energy can be saved by VO. Manufacturers of VO devices do not undertake comprehensive surveys of the connected load. Some simply consider the existing voltage readings at the main incoming LV terminals to your site/facility and the furthest socket outlet in the installation from this point. These voltage readings will dictate the maximum voltage that can be reduced on your site/facility without exceeding the lower statutory limit. Your site's projected savings is then based on this reduced voltage.

7.1 Conservation Voltage Reduction (CVR) Factor determines the how effective VO is in reducing energy consumption for a particular installation or load make-up. The higher the CVR Factor the greater the savings.

$$\text{CVR Factor} = \frac{\%\text{E (\% energy reduced)}}{\%\text{V (\% voltage reduced)}}$$

7.2 As an example, a supplier may consider that you will achieve 13% (%E) in energy savings by reducing the voltage by 8% (%V). In this case CVR Factor = 13/8 = 1.625. It is stressed that the actual savings achieved is dependent on the type of load and the CVR factor varies considerably depending on the type of connected load.

7.3 The CVR Factor quoted by manufacturers is for linear loads, such as filament lamps, strip heaters, cooking stoves, kettles and boilers. In practice any installation will have a mixture of both linear and non-linear loads (such as fluorescent lighting, motors, compact fluorescent lamps, electric welding machine and computers) and this rule of thumb is far from remotely accurate. Studies carried out in the USA[13] showed that the actual CVR factor varied from 0.336 to 1.103 depending on the load type. This is well below that claimed by suppliers in the UK, which may in part be attributable to technological advances made since the study carried out in 1991.

Additional Information Required by the Manufacturer

8.0 The following information will be sought by the manufacturer of the VO device, in order for them to estimate savings, payback period and return on investment (ROI):

[13] Kennedy BS and Fletcher RH "Conservation Voltage Reduction (CVR) at Snohomish County PUD", IEEE Transactions on Power Systems, Vol 6, No 3 August 1991

8.0.0 For LV Single-supply Sites

- The highest maximum demand (in kW or kVA) in the last year for the incoming supply to your building. These figures will determine the rating of the VO device.

- The total kWh consumption for the last 12 months on the incoming supply.

- From this they will also estimate the cost per kWh, including Climate Change Levy if appropriate, that you will be paying for next year or two.

8.0.1 For HV Sites with Multiple Transformers, or Sites with Multiple LV Supplies

- The highest maximum demand (in kW or kVA) in the last year for each of the incoming supplies to your site (measured downstream from the HV transformer). These figures will determine the rating of the VO device.

- The total kWh consumption for the last 12 months on each supply.

- From this they will also estimate the cost per kWh, including Climate Change Levy if appropriate, that you will be paying for next year or two.

8.1 Energy consumption data such as half hour consumption, maximum demand, annual consumption etc can be obtained from MOD's energy data provider via the dedicated web site. The current provider, till Oct 2011, is IMServ and their Energy DataVision web portal: https://edvplus.im-serv.com. Unit cost data can be found on the utility bill.

ANNEX C – ROLE OF THE AUTHORISING ENGINEER

1.0 With the exception of small sized VO equipment for lighting circuits and individual motors the MMO site manager must consult the Authorising Engineer (Electrical), (AE), as soon as the installation of the VO equipment is being considered. As the technical authority for ensuring that the proposed equipment meets the specification and that the proposed installation complies with statutory and MOD mandatory requirements, the AE must approve the installation of such devices. Where applicable, the AE also needs to be satisfied the planned installation is undertaken in accordance with the MOD Safety Rules and Procedures as prescribed in JSP 375 Volume 3, Chapter 3 and BS 7671:2008[14]. The AE will discuss the proposal with the MMO and ensure that there are no technical issues that would deny the installation of the VO device.

1.1 It is not the AE's responsibility to confirm that energy savings are achievable or to deny the installation of the VO device based on the premise that energy savings may not be achievable. The AE's role is primarily to ensure that safety requirements are met with respect to the proposed installation and the safety of the existing installation is not adversely affected by the addition of the VO device.

1.2 Once the contract has been let other technical information, such as the impedance and fault withstand capability of the equipment, must be provided by the manufacturer to the AE for approval. The manufacturer is also required to submit installation drawings, along with safety method statements and delivery programme to the AE.

1.3 If the AE is not satisfied with the proposal for technical reasons the manufacturer/ supplier of the device must ensure that solutions to his concerns are met at the planning stage. In the extreme case where the AE feels that the VO device is incompatible with the existing installation he can deny the installation of such equipment. So in order that the procurement and installation of the VO device is executed without technical problems arising at a later stage it is imperative that the AE is engaged in the process right from the outset by the MMO.

[14] 17th Edition IEE Wiring Regulations: Requirements for Electrical Installations

ANNEX D – STATUTORY REQUIREMENTS

Electricity at Work Regulations 1989 (EAWR)

1.0 In order to comply with EAWR the following fundamental requirements must be met prior to the installation of the VO device:

1.0.1 Regulation 5:

- Where the device installer seeks to install the device within subsisting equipment the OEM for that equipment must be contacted for assurance that the installation will not compromise the strength and capability of their equipment. Particular consideration must be given to electrical clearances, fault level capability and basic insulation level. An example where this may be pertinent is when the VO device is proposed to be installed alongside an existing feeder pillar.

- The equipment supplier or installer must confirm in writing that the equipment is suitably rated for the fault level at the point of installation and will not contribute to an increase in down stream fault level.

- Where the equipment contains harmonic traps or similar devices the equipment supplier shall confirm in writing that the equipment is suitably rated for the level of harmonics present on the system proposed for the installation.

1.0.2 Regulation 11:

- The equipment supplier or installer must confirm in writing that the equipment will not adversely affect the operation of down stream protective devices.

Electricity Safety, Quality and Continuity Regulations 2002 (ESQCR)

2.0 In order to comply with ESQCR the following fundamental requirements must be met prior to the installation of the VO device:

2.0.1 Regulation 8(3)c:

- The equipment supplier or installer must confirm in writing that the equipment does not insert an impedance into the LV earth path to the supply source.

2.0.2 Regulation 8(4):

- The equipment supplier or installer must confirm in writing that the equipment does not result in a Protective Multiple Earthing connection within the consumer's installation.

2.0.3 Regulation 21:

- It should be noted that where the installation operates a LV switched alternative to the normal distribution i.e. LV generation or Uninterruptible Power Supplies (UPS) then compliance with BS 7671 is a legal requirement. Protective relay settings may also need to be readjusted so that they operate effectively under the reduced voltage.

Compliance with BS 7671:2008

3.0 Notwithstanding the above statutory requirements all VO installations designed after July 2008 should comply in all respects with BS 7671:2008. One of the fundamental requirements is the need to recalculate the Zs for the new lower voltage to ensure that protective devices operate as originally designed.

From Regulation 411.4.5:

$Zs \times Ia \leq Uo$

Where:

Zs is the impedance in ohms (Ω) of the fault loop comprising:

- the source
- the line conductor up to the point of the fault, and
- the protective conductor between the point of the fault and the source.

Ia is the current in amperes (A) causing the automatic operation of the disconnecting device within the time specified in Table 41.1 of regulation 4111.3.2.2 or, as appropriate, Regulation 411.3.2.3. Where an RCD is used this current is the rated residual operating current providing disconnection in the time specified in Table 41.1 or Regulation 411.3.2.3.

Uo is the nominal a.c. rms or d.c. line voltage to Earth in volts (V).

3.1 As an example, let us say a VO device is installed to reduce the voltage to new Uo of 220 V. We now need to determine the new value of Zs which must not be exceeded if the protective device is to operate within designed parameters. Assuming we have a 32 A Type B circuit breaker protecting a final circuit to disconnect within 0.4 s, then maximum permissible earth loop impedance:

$Zs = Uo/Ia = 220/160 = 1.375\ \Omega$. This compares with 1.44 Ω at Uo of 230 V.

3.3 Table D1 gives values of Zs at different values of Uo for Type B circuit breakers to BS EN 60898 to achieve 0.4 s disconnection. Figure D1 is the graphical representation of these values. It becomes clear that with reduced voltage the Zs also reduces and it must be ascertained that the measured Zs is not greater than the calculated value.

Uo derived from	Uo (Volts)	Type B Circuit Breaker Rating (Amps)											
		6	10	16	20	25	32	40	50	63	80	100	125
BS 7671:2001[15]	240	8.00	4.80	3.00	2.40	1.92	1.50	1.20	0.96	0.76	0.60	0.48	0.38
BS 7671:2008[16]	230	7.67	4.60	2.87	2.30	1.84	1.44	1.15	0.92	0.73	0.57	0.46	0.37
Calculated[17]	225	7.50	4.50	2.81	2.25	1.80	1.41	1.13	0.90	0.71	0.56	0.45	0.36
Calculated[18]	216	7.20	4.32	2.70	2.16	1.73	1.35	1.08	0.86	0.69	0.54	0.43	0.35

Table D1: Values of Maximum Earth Loop Impedance (Zs) in Ohms for Type B circuit breakers for 0.4 s disconnection time at various values of Uo.

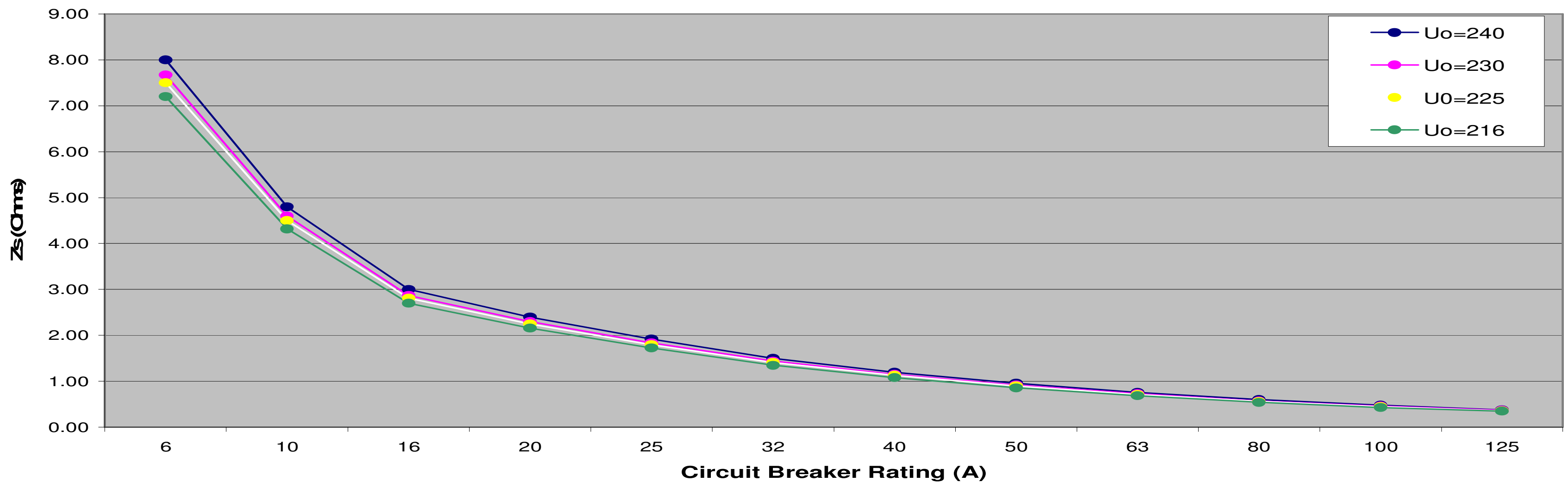

Figure D1: Values of Maximum Zs for Type B Circuit Breakers for 0.4 s disconnection time at various values of Uo.

15 From BS 7671:2001 Table 41B2
16 From BS 7671:2008 Table 41.3
17 Typical VO voltage
18 Typical VO voltage

ANNEX E – VOLTAGE OPTIMISATION - CHECKLIST FOR THE ENERGY MANAGER

Phase 1 - Investigation Stage				
Serial	Check	Yes	No	Comments
1	Discuss proposal to identify if VO equipment is suitable for energy reduction on site with MMO. Confirm what costs are payable to the MMO for the production of a Preliminary Study Report to include: • Initial load survey findings • Rough order of costs for the installation of VO equipment, if appropriate • Simple Payback Period Calculation and value for money for the scheme			
2	Secure funding for the first phase of the works mentioned at Serial 1 and order the works on MMO in accordance with local procedures			Funding for the preliminary study report including initial connected load survey
3	Independent initial connected load survey complete			
4	Would any connected load suffer from VO? If so, can these be replaced, modified or adjusted to render them suitable and beneficial for use with VO			
5	Is VO a viable option for energy reduction?			If no, abandon proposal
6	Are there any opportunities for energy savings to be achieved immediately through VO			
7	Any irresolvable technical issues?			If yes, abandon proposal
8	Rough Order of Cost from MMO			Attach to business case
9	Simple Payback Period from MMO			Attach to business case
10	Value for Money Check (including whole life cycle costs) from MMO			Attach to business case
11	Submit Business Case for the second phase of the works			
12	Funding approved?			Funding for procurement of VO
13	Programme in works with MMO			Minor New Works
Phase 2 - Procurement Stage				
14	MMO invites tenders from VO equipment manufacturers iaw MOD rules			
15	MMO receives technical submissions from bidders			MMO & AE to review
16	Contract awarded and equipment ordered by preferred bidder			
17	MMO conducts independent initial electrical energy survey over 4-week period			4-weeks prior to VO equipment installation
18	MMO measures Zs values for circuits protected by the highest and lowest rated protective devices downstream of proposed VO device			Prior to VO equipment installation
19	Any unresolved technical issues?			Must be resolved prior to installation of equipment
20	VO equipment installation completed by supplier and handover complete with relevant documents. Zs values measured by supplier to confirm operation of protective devices unaffected for the highest and lowest rated circuits downstream of the VO device			
21	Post installation independent electrical energy survey over 4-week period through MMO			
22	Compare benefits as claimed by supplier. Are all claims met?			If no, consider removal of VO at supplier's expense, seek full reimbursement & inform DE P&TS. If yes maintain data and inform DE P&TS