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FINAL REPORT

Investigation into Voltage Optimisation Technology for Abattoirs

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1.0 EXECUTIVE SUMMARY

Optimizing voltage levels to a controlled stable level at a facility can not only reduce the cost of energy but also enhance equipment performance, reduce maintenance costs, prolong equipment life and reduce green house gas (GHG) emissions. Voltage optimisation (VO) technology has been widely used in a number of different industries locally and internationally, but not to a large extent within the red meat processing sector in Australia. To determine whether VO technology can be implemented, and whether it is technically and economically viable for red meat processing sites, this project investigated the potential effectiveness of VO technology in Australian abattoirs though case study analysis. The project started with an extensive desktop review of the existing literature. This was followed by the collection of load and equipment profiles and monitoring voltage and power quality data at two representative processing sites to investigate the available voltage optimization technology suitable for the Australian meat processing industry. The investigation explored the most suitable VO technology considering the implications for the plant and equipment under operation at a processing plant by using existing published research, input from equipment suppliers, and through rigorous analysis based on case

studies at representative meat processing sites.

The first part of the study entailed a desktop review of voltage optimisation technologies for red meat processing facilities with a focus on Australian abattoirs. The review included different types of voltage optimisation technologies currently available and entailed examination of their technical performance characteristics and corresponding economics. This review highlights the techno-economics of various case studies in which voltage optimisation devices were deployed in similar processing industries (e.g. beverage manufacturing) or industries with similar technologies (e.g. cold storage) as well as meat processing industries/abattoirs in other countries. The review gives a clear indication of the need and considerations to deploy voltage optimisation technology in Australian abattoirs. From the review of the literature it was evident that there is a significant scope for the Australian red meat processing industry to reduce their energy consumption and improve power quality by optimising the voltage level through the application of voltage optimisation technologies.

However, to determine whether voltage optimisation can be implemented, and whether it is economically worthwhile for Australian red meat processing sites, it is important to analyse the sites' electricity consumption profiles and cost savings opportunities. Therefore, the second part of the study investigated electricity usage data at two typical red meat processing sites and performed an analysis of electrical load and power quality (PQ) issues to determine whether voltage optimisation can be applied. The two representative sites are presented as Case Study Site 1 and Case Study Site 2. Case Study Site 1 is located in Westen Australia and Case Study Site 2 is located in Queensland. The analysis showed that voltage coming from the grid can be highly variable for both the Western Australian and Queensland sites. This voltage variability seems to occur irrespective of which electricity network the red meat processing facilities are connected to, which presents the same implications for abattoir equipment. Through analysis of collected electricity characteristics (e.g. voltage, current, power factor) and power quality (harmonic distortion and under voltage, overvoltage events) data over time at the two case study sites it can be expected that most abattoir sites would be able to save energy and improve PQ with the targeted implementation of voltage optimisation equipment.

The analysis of Case Study Site 1 showed that, if 230 V could be supplied and maintained for one of the main transformers alone (servicing the slaughter floor), then annual energy savings could potentially be ~ 70,348 kWh. On the other hand, from the analysis of Case Study Site 2 it was calculated at the site level that a maximum of ~122,758 kWh of energy could be saved per year. However, energy and associated costs savings are mostly dependent on the size and type of the connected loads, voltage profiles and power quality attributes which vary from site to site, and even from transformer to transformer within a site.

Then, a techno-economic analysis of the use of voltage optimization in the red meat processing industry was undertaken. The analysis used measured electricity profiles from two typical medium sized abattoirs to determine the potential electricity savings and payback periods for using voltage optimization. The analysis included a sensitivity analysis around key factors including the price of electricity, facility/electrical feeder size (electricity consumption) and load type, supply voltage and optimizer type (dynamic or static). The results have shown that there are technical and economic benefits to the installation of voltage optimisers in red meat processing facilities. For a typical medium sized red meat processing facility with electricity supplied at 240 volts the installation of a dynamic voltage optimizer will have a payback period of between 3 and 6 years. Apart from the direct economic benefits due to reduced electricity consumption there are additional benefits from increased electrical equipment lifetimes and reduced maintenance costs. Depending on the voltage optimizer and technology used there can be additional savings from an improved power factor and reduced harmonic losses. The widespread use of voltage optimisers within the industry would in most cases increase its cost effectiveness and competitiveness.

Finally, the project has developed a Voltage Optimisation Guide specifically for Australia abattoirs with the aim to provide the necessary tools and guidance to support a preliminary assessment of VO technology at a site level.. The output of the project will enable engineering and operations staff to be better informed about the economic and technical benefits (and possible issues) of using voltage stabilization and optimization technologies in a current ready to use manner.

2.0 INTRODUCTION

Energy costs are one of the major operating costs in the meat processing industry in Australia (AU$1M to AU$2M per year each in the top 25 processing plants), with primary energy sources including electricity and natural gas [1]. In a meat processing facility, electricity is predominantly used for refrigeration, compressed air, processing equipment and lighting, and gas is used for hot water and steam systems. Generally, the supply voltage maintained by the network operator is higher than the optimum operating voltage required for most of the equipment in meat processing facilities [2]. To ensure adequate power quality (PQ) and reduce energy costs, it is essential to maintain a regulated electricity supply that is optimal. As well as leading to inefficient use of energy in the equipment, over-voltage tends to cause overheating and shorten equipment life.

According to the current AS60038 Standard Voltages standard [3], single phase and three phase supply voltage is 230V and 400V respectively with a tolerance between +10% and -6% and a utilization range of +10% and -11%. However the local operators often still follow the old standard, for example Ergon Energy in Queensland uses 240V±6% and 415V±6% for single and three phase systems respectively [4]. Electrical equipment connected to the electricity network function optimally at 220 – 230V and sometimes even as low as 200V. There are a number of reasons that network operators maintain the voltage at the higher end of standard limits including to avoid voltage drop at the end node, accommodating loss in transmission and avoiding financial loss due to lower voltage at the customer end. In many cases most of the equipment experiences an overvoltage condition at its input. However, if the actual supply voltage is higher than the minimum requirement of any equipment, then the equipment will often consume more energy. Therefore, a key challenge is to maintain supply voltage at the equipment's optimal voltage level whether using only the grid as an electricity source or combining the grid with on-site electricity generating sources.

There is significant scope to reduce energy consumption by optimizing the voltage level. Each of the applications at meat processing plants requires a specific current, voltage and frequency in order to ensure adequate PQ and minimal energy consumption. Therefore, voltage compensation or optimization is an essential requirement today, which can also help improve the power factor, reduce harmonic voltage deviations, and, can most importantly significantly reduce energy consumption and carbon emissions for the red meat processing industry. Voltage optimization technologies have been used by many other industries internationally and locally however their use has not yet been publicly reported within the red meat processing sector in Australia. The evidence from application in other related industries is that there is a significant scope to reduce energy consumption by optimising the voltage level in facilities in the meat processing industry. Each piece of electrical equipment at meat processing plant is designed to operate at a specific current, voltage and frequency to ensure adequate power quality and minimal energy consumption [5 - 6]. Recently for the NSW Department of Environment and Heritage [7] SMEC has developed a general voltage optimisation guide that assists in analysing the potential benefits, and respective issues, of deploying voltage optimisation technology in various industries.

To determine if there is a case for the adoption of voltage optimization technology for the Australian meat processing industry a detailed investigation was required to understand the nature of the electricity supply from the network, the electrical equipment used in the industry and its corresponding operating conditions. This understanding was needed in order to correctly determine the potential economic, environmental and social benefit to be gained in a meat processing facility after integrating voltage optimization technology. Therefore, this study has explored the present operating conditions in representative red meat processing facilities in Australia and in particular PQ issues such as current and voltage level and stability and in light of this investigated available voltage optimisation technologies. After a thorough techno-economic it has been confirmed that voltage optimization technology is recommended for the Australian meat processing industry and its implementation can achieve significant energy and cost savings.

3.0 PROJECT OBJECTIVES

The objectives of the overall project include:

- Identification and reporting of the profile of electric equipment used in representative meat processing facilities, the current level, condition, and issues (if any) of supplied voltages and power.
- A list of suitable voltage optimiser technologies and producers in the market and recommendations about the suitable voltage optimisation/stabilisation technologies/solutions for representative meat processing facilities in Australia.
- A comparison study of voltage stabilisation with voltage optimisation and a discussion of the potential implications for plant and equipment operating at the facility.
- Development of an economic model to identify the techno-economic feasibility of voltage optimisation technology for Australian abattoirs.
- Develop a Voltage Optimisation (VO) Guide for the red meat processing industry; and
- Present the project results in a final report and snapshot summarising the findings.

4.0 METHODOLOGY

Initially, an extensive literature review was conducted to investigate the voltage optimisation and stabilization technologies currently used in other related sectors and internationally in the meat processing industry with their technical and economic performance characteristics. Secondly, catalogues of the equipment, measured load profiles, and grid PQ analyses for two abattoir case study sites were used to identify the extent of possible improvement to PQ and energy savings opportunities from the use of voltage optimisers. A techno-economic analysis was then undertaken to identify suitable VO technology solutions for the Australian meat processing industry. Finally, a VO Guide has been developed which will be a resource for the industry to assist in selecting the most suitable VO technology for specific Australian meat processing facilities. The methodology of the study is shown in Figure 1.

Literature Survey	Power Quality Analysis	Techno-Economic Analysis	Voltage Optimisation Guide
• Scientific, technical and engineering literature. • Case studies.	• A plant inventory list of main electrical equipment on-site (e.g. type, make, ratings age, model, ratings and use). • Typical hours of operation of site. • Daily and weekly voltage profile for both summer and winter season. • Abattoirs' operating conditions and energy usage patterns. • Power Quality analysis.	• Technical analysis of potential energy savings. • Identify commercially available and applicable voltage optimisation technologies. • Document deployment costs. • Economic analysis of VO technology.	• A clear decision-making framework. • Identifying implementation barriers and corrective actions. • Guidance to ultimately assist the user to make an informed decision about voltage optimisation.

Figure 1: Methodological approach of the study

4.1 Literature Review

- Understand the major energy consuming processess and equipments at a typical abattoir.
- Understand the typical energy consumption of an abattoir including daily, weekly and yearly energy consumption.
- Types and methods of VO technologies.
- Compare the technical performance characteristics of available VO technologies.
- Identify barriers to the uptake of VO.

4.1 Data Collection and Analysis

- Data was collected to determine the voltage and power quality profiles at two representative red meat processing sites; one from Western Australia (Case Study Site 1), and another from Queensland (Case Study Site 2), including major equipment types and their usage profiles.
- Power network operating condition data has been collected using a Fluke Power Quality Analyser to explore power quality issues such as voltage fluctuations, harmonics and power factor.
- The equipment profile information has been collected through the relevant engineering or other staff at the selected meat processing plants and manufacturing specification sheets or other information sources.
- Through analysis of the data the current voltage related challenges in the industry including PQ issues have been canvassed.

4.3 Techno-Economic Analysis

- Based on the case study sites a techno-economic analysis of the use of voltage optimization in the red meat processing industry was undertaken.
- A sensitivity analysis around key factors including price of electricity, facility/electrical feeder size (electricity consumption) and load type, supply voltage and optimizer type (dynamic or static) was conducted.
- The energy savings and payback period with various sensitivity variables were analysed to evaluate the effectiveness and usefulness of voltage optimisation technology for abattoirs.

4.4 Voltage Optimisation Guide

The outcome of the research has enabled the project team to identify key aspects of voltage management relevant to the red meat processing industry, including best practice, new technology, trends, lessons learned from other jurisdictions and alternative technologies. The project team used this research along with the techno-economic analyses carried out using the two representative sites to develop a VO optimisation guide tailored to the red meat processing industry. This includes the provision of:

- A clear decision-making framework (i.e. a process flow diagram) developed on the basis of understanding the impacts of VO (both positive and negative) and managing risk.
- Identifying implementation barriers and corrective actions.
- Consideration of alternative measures and technologies.
- Clear, non-technical background information regarding voltage management /optimisation.
- Development and reference to real-world and transferable case studies; and
- Guidance to ultimately assist the user to make an informed decision about VO.

5.0 PROJECT OUTCOMES

5.1 Literature Review

5.1.1 Electricity Consumption in Abattoirs

In a meat processing facility electricity is predominantly used for refrigeration, compressed air and lighting while gas is used for hot water and steam systems [1]. Most meat processing facilities can be categorized according to the activities performed at the facility and these can include:

a) Slaughter only or Boning only.
b) Slaughter and Boning.
c) Processing; or
d) Rendering.

Under the Domestic Processors Energy Efficiency Program (DPEEP) [1] five meat processing sites were surveyed to investigate energy consumption from each major energy service or equipment type based on rendering or non-rendering sites as shown in Figure . The main energy consuming services/equipment includes refrigeration (15-31%), steam and hot water (53-77%), pumping (3%), lighting (3%), processing equipment (2%), conveyors (1%), packaging equipment (1%) and air compressors (1%) [1].

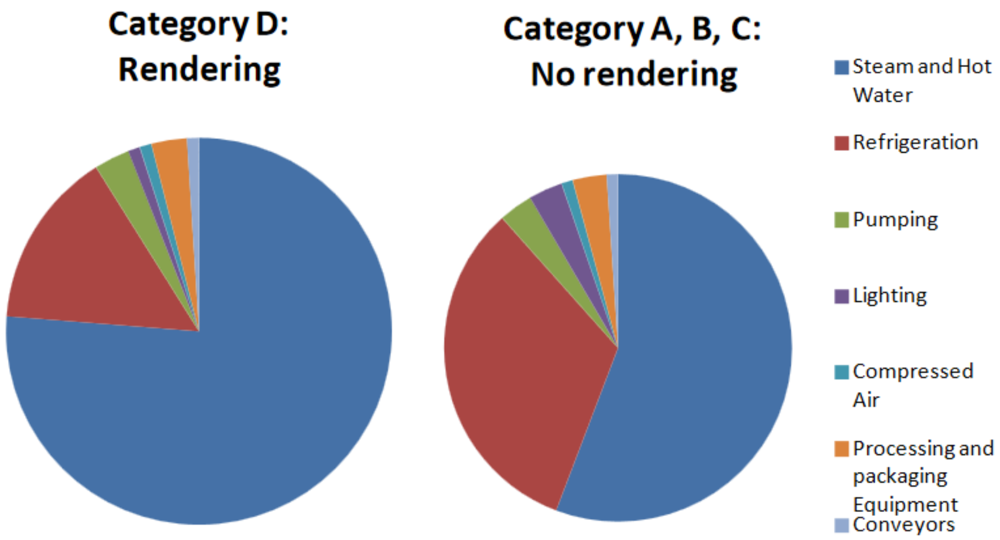


Figure 2: Breakdown of energy consumption by major energy service or equipment for rendering and non-rendering sites [reproduced from 1]

On a day-to-day basis, typical electrical load profiles for a meat processing facility in Australia reveal that electric power consumption is the highest during boning and the initial stages of carcass cooling which occurs from 05:00 to 14:30, Monday to Friday as shown in Figure 3. As compared to a typical weekday, which has distinct peaks throughout the day, the typical weekend electricity consumption is relatively constant throughout the day.

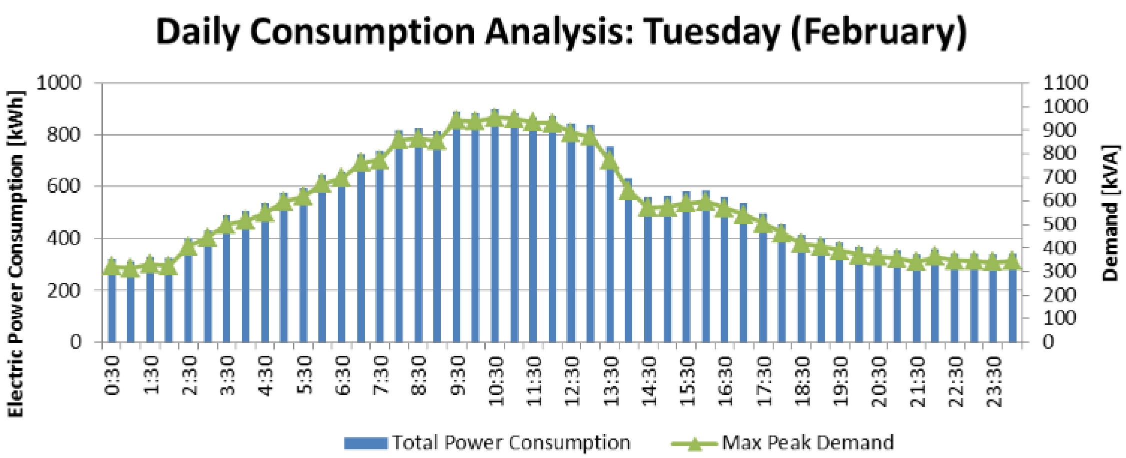


Figure 3: Typical weekday electricity consumption profile for an Australian meat processing facility [reproduced from 1]

From analyses undertaken in the Domestic Processors Energy Efficiency Program [1], electricity consumption increases during summer due to additional cooling and refrigeration as shown in Figure 4.

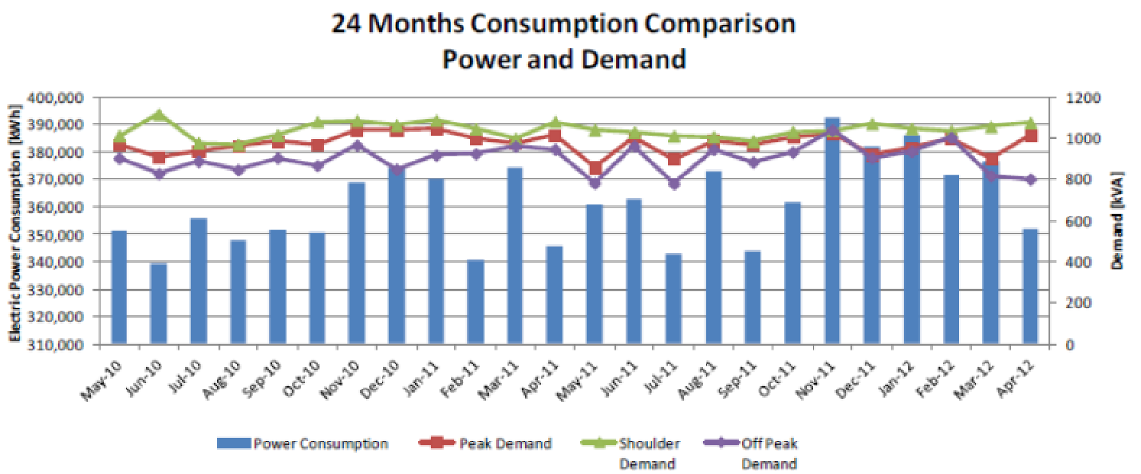


Figure 4: Typical weekend electricity consumption profile for an Australian meat processing facility [reproduced from 1]

What can be gleaned from typical energy consumption quantities, proportions, and usage patterns in Australian red meat processing facilities is that there is significant potential for reducing the electricity consumption by reducing the supply voltage to an optimum level, regardless of whether the site has rendering or non-rendering activities.

5.1.2 Voltage Optimisation

All electrical and electronic systems are designed and manufactured to operate at maximum efficiency with a given supply voltage, called the *nominal operating voltage*. The electricity supply voltage, which is maintained by the network operator, is usually higher than the optimum (nominal) operating voltage required for most of the equipment in facilities. A facility's voltage supply can also suffer from voltage surges, over voltage (spikes), under voltage (sags) and harmonic losses.

In order to ensure adequate power quality and reduce energy costs it is essential to maintain a regulated electricity supply that is stable at the equipment's optimal operating voltage whether using only the grid as an electricity source or combining the grid with on-site electricity generating sources. Voltage optimisation aims to reduce electricity usage, power demand and cost by reducing supply voltage 'downstream' of the meter. The technology can also improve power quality by reducing harmonic and transient voltages, as well as balance phase voltages [1, 8]. A reduction and balancing in electricity supply voltage provides a saving in energy consumption (kWh) and a reduction in maximum demand (kW and kVA) which results in a reduction in electricity bills for the consumer [9 - 10]. Other purported benefits include improved power quality, less equipment maintenance, improved equipment life and reduced energy consumption, which all lead to significant cost savings [11].

When incoming voltages exceed the required equipment voltages, energy gets wasted in the form of heat. This results in wasted costs (since the electricity will have already been paid for once it passes the meter) and potentially reduces the lifespan of electrical appliances. As a rule, the power demand will increase with an increase in supply voltage magnitude and vice-versa. In effect, 1% of voltage increase leads to 1% increase in energy consumption and 1.7% or more increase in reactive power consumption (depending on load types and power factor).

Energywise [5] performed data logging across Australia and found that approximately 90% of sites are operating at an over-voltage level, with an average of approximately 240V. For consumers, the benefits include reduction in energy consumption and therefore electricity bills, removal of harmonics (which generally cause overheating, misfiring in variable speed drives and torque pulsations in electric motors), reduction of transients (over- or under-voltage), improved power factor which reduces reactive power and an overall reduction in maintenance costs [9, 10].

5.1.3 Voltage Optimisation Methods

Voltage optimisation is considered a component of voltage management. Depending on how voltage may impact the operations and the productivity and performance of an abattoir's equipment voltage management may include [12]:

- Voltage stabilisation (e.g. manages electrical transients).
- Voltage regulation (e.g. controls over and under voltage).
- Voltage reduction (e.g. reduces voltage by a selectable percentage); and
- Voltage optimisation (e.g. adjusts voltage to a certain range).

Voltage stabilization and voltage regulation are both ways of protecting equipment from variations in voltage (either fast short period transients, or slower longer periods of over- or under-voltage). Both devices do not change the underlying supply voltage but adjust the voltage around the supplied grid voltage and ensure this voltage is maintained. Voltage reduction and voltage optimization are both ways of reducing the voltage to a set value to realise energy savings. Common types of voltage optimization units with their strengths and weaknesses are presented in Table 1.

Table 1: Common types of voltage optimization unit [12 – 13]

TYPE	DESCRIPTION	BENEFITS	ISSUES
Fixed Voltage Regulators	Fixed voltage regulators are basic voltage optimisation units that step down the voltage by a fixed amount (e.g. 5%). The units deliver a varying output (i.e. with the same variations as the supply) at a lower voltage than the supply. These units use magnetic couplings that transmit an electric load and use a secondary winding that applies an induced opposing voltage. They do not reactively adjust to voltage supply levels.	• Generally cheaper than dynamic systems. • Small sized unit. • Ideal for a site where the voltage supply levels are relatively stable.	• Does not actively compensate for voltage fluctuations in the supply. • Risk associated with under voltage (i.e. these units may supply voltage that is lower than the rated voltage in the event of a dip in voltage supply).
Dynamic System – Voltage Optimisers	Voltage optimisers aim to dynamically adjust voltage levels within a specific range. This output is aimed to supply a specific voltage required by certain electrical equipment. Most voltage optimisers use electronic controls that can adjust voltage within a specified bandwidth. This is achieved by continually comparing the incoming voltage to the voltage needed to drive the loads. Some voltage optimisers may also contain features to address other power management elements such as harmonics, transients and power factor.	• Voltage optimisers are used to adjust supply voltage to a more precise and steadier level. This enables the user to supply voltage closer to the equipment's power rating resulting in greater energy savings.	• Voltage optimisers are typically more expensive than voltage regulators. • Does not compensate for voltage drops in the supply (some voltage optimisers have protection against voltage drop). • Depending on the unit, the voltage optimisers are generally larger than voltage regulators.

Dynamic System – Boosted Voltage Optimisers	Other electronically controlled voltage optimisers are capable of boosting voltage to safeguard voltage supply in the event of voltage drops.	• Generally used when the voltage drops regularly below the desired level. • May be suitable for end users with variable voltage supply.	• Additional costs for the voltage booster. • Not widely used in Australia as the voltage does not usually drop to levels below the minimum allowable level (i.e. 216V).

5.1.4 Configurations and Applicability of Market Offerings for Australian Red Meat Processing Industry

The typical configuration for VO units is to integrate them into the main switchboard, or main supply transformer (Figure 5a) or individual LV transformer (Figure 5b), within a distribution board, or on specific pieces of equipment. This ultimately depends on the size of the site, load size and, operational criticality of equipment, voltage sensitivity or non-sensitivity, and the economics of doing so. For example, the iESCo's Power Perfector units, most of Ortea's products except OPTInet series, both of PowerSines' offerings, Powerstar's Powerstar and Powerstar Max, and both of Schneider Electric's products would be installed or incorporated into an abattoir's main switchboard or a local distribution board, or on specific equipment. Ortea's OPTInet products and Powerstar's Powerstar MAX HV could be integrated with a step-down transformer on-site (notwithstanding there would be an approvals process with the electricity utility company).

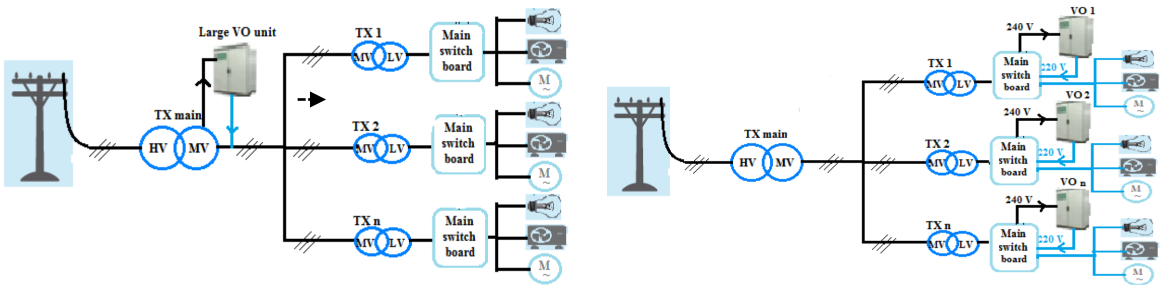


Figure 5: Possible location of VO unit installation in a typical abattoir (a) with main transformer and (b) with individual LV transformer

Voltage optimisation technologies that are currently widely used in different countries around the world in the meat industry as well as in the other industries were presented in detail in the Milestone One report. Table 2 presents case studies of different types of VO technologies currently used in meat processing industries throughout the world together with their voltage optimization, energy savings and cost-effective scenarios.

Table 2– Case studies for meat processing industry [14 - 16]

Location	Project	Technology	Energy Savings Cost Savings ($AUD)	Payback Periods	Comments
Grannagh *Ireland* [14]	Dawn Pork & Bacon	Powerstar HV MAX	11.3% per year $88,222 per year based on 17c/kWh	3 years	Energy savings based on 6-week pre- and post-installation data
			9.8% per year $76,244 per year based on 17c/kWh	3.4 years	Energy saving considered LED light and 6-week pre- and post-installation data
Holycross *Ireland* [14]	ABP Rathkeale	Powerstar HV MAX	10.7% per year $48,703 per year based on 12.4c/kWh	4.3 years	Energy saving based on 26 days pre- and post-installation data
Israel [15]	The Moses Chicken Farm	PowerSines 125A	11.5% per year	1.8 years	Voltage reduced from 235V to 218V
Yorkshire *England* [16]	Pig Rearing Farm	VO4 unit 100Amp	12 MWh per year $2,452	1 year	Energy savings based on 4-month pre- and post-installation data

The benefit in the form of energy and cost savings from voltage optimisation is highly dependent upon the existing site voltage, the size of the voltage tapping applied and the proportion of voltage-dependent equipment on site – none of which can be reliably predicted without a detailed feasibility study. The higher the supply voltage is, the greater the potential to make energy savings. To ensure optimum savings and performance a comprehensive analysis of a building or site's power conditions should be completed prior to installation.

5.1.5 Alternatives to Voltage Optimisation Management

There are other methods to managing and optimizing voltage that might be considered as a complementary activity to installing VO technology. Of course, this ultimately depends on the severity or instability of the voltage supplied to an abattoir, and is simply discussed here for completeness.

If over- or under-voltage is a significant issue, the following might apply:

- Detailed power quality assessment.
- Load balancing i.e. alteration to operating sequence, start-up/shut-down etc.
- Installation of power conditioning equipment.
- Replacement of equipment with new equipment that have wider voltage tolerances. or
- Installation of over- and under-voltage protection.

Other options for consideration might include modifying voltage from the incoming transformer (high- and medium-voltage sites with onsite utility transformer), or replacing voltage sensitive equipment with voltage insensitive equipment (wherever applicable).

5.2 Data Collection and Analysis

This part of the report presents energy consumption scenarios of two selected Australian abattoirs and discusses the type of electrical equipment present on a typical abattoir site, and the contribution made by different areas to the load profile. Real-time power monitoring devices have been used to collect the power network operating condition data for the representative sites including, where relevant, the physical quantities such as total energy consumption, voltages and currents and voltage fluctuations, in the different phases as well as power factors and total harmonic distortion in order to investigate the suitability of using VO for those typical sites.

5.2.1 Electrical Equipment Types and Loads at a Typical Abattoir

Based on the electrical layout and distribution for a typical (Monbeef, Cooma) small red meat abattoir site [17] and data collected at a case study site representing a medium sized abattoir typically the electrical distribution (via transformers and or switch boards) can be divided into the following areas (with rough percentage of consumption):

- Refrigeration - 50 %.
- General production (kill floor, boning room) – 23%.
- By-products/rendering – 15%.
- Office, workshops, amenities and auxiliary services (e.g. boilers etc.) – 5%.
- Water pumps (5%). and
- Dams (agitators and pumps etc.) - 2%.

5.2.2 Data Collection and Analysis for Case Study Site 1

5.2.2.1 Data Collection

There are seven main transformers that supply the electricity to the equiptment of this site. The annual electricty consumption of this representative site is approximately 15,800 MWh. This facility has no power generation on-site and electricity is only supplied from the main grid by Western Power, the Government owned transmission and distribution company. The abbatoir is at the end of the feeder line and is known to have lower voltages and regular periods of power drop.

The electricity data was collected from the four most heavily loaded of the seven transformers. The specifications of the monitored transformers are:

- Refrigeration Feeder - Transformer 1 (TX1)

The capacity of TX_1 is 1 MVA. This transformer supplies the main part of the refrigeration plant and the boning room loads.

- Kill Floor Feeder - Transformer 2 (TX_2)

The capacity of TX_2 is 1 MVA. This transformer supplies the kill floor motor control, air compressors and plate freezer switchboard.

- By-Products Feeder - Transformer 3 (TX_3)

This transformer supplies the By-products Motor Control Centre and the site fire pumps.

- General Distribution Feeder - Transformer 6 (TX_6)

The capacity of TX_6 is 1.5 MVA. This transformer supplies part of the refrigeration plants and general loads.

A power quality analyzer (Fluke 435 Series II Power Quality and Energy Analyzer) [18] was installed (as shown in Figure 6) at each of the transformers on-site for a week to measure the electricity data at 1 -minute intervals. The electricity data collected from the individual transformers were: phase and line voltages; phase and line currents; active power (per-phase and total); reactive power (per-phase and total); apparent power (per-phase and total); voltage and current unbalances; power factor; total harmonic distortion; and a number of other relevant parameters.

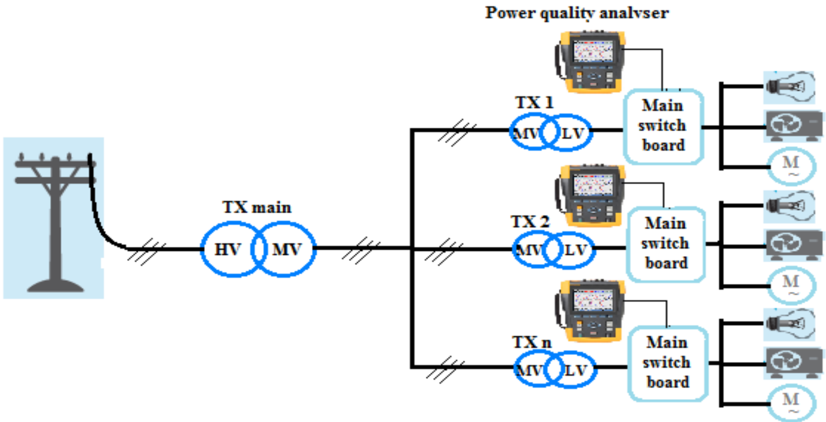


Figure 6 – Data collection from case study 1 abattoir using a Fluke Power Quality Analyzer

5.2.2.2 Load and Voltage Profiles

The following sections present the load and voltage profiles for the refrigeration, kill floor, by-products, and general distribution (with some refrigeration) feeder transformers at the abattoir. The deviation from the average supply voltage and weekly voltage frequencies are also presented for each of these transformers.

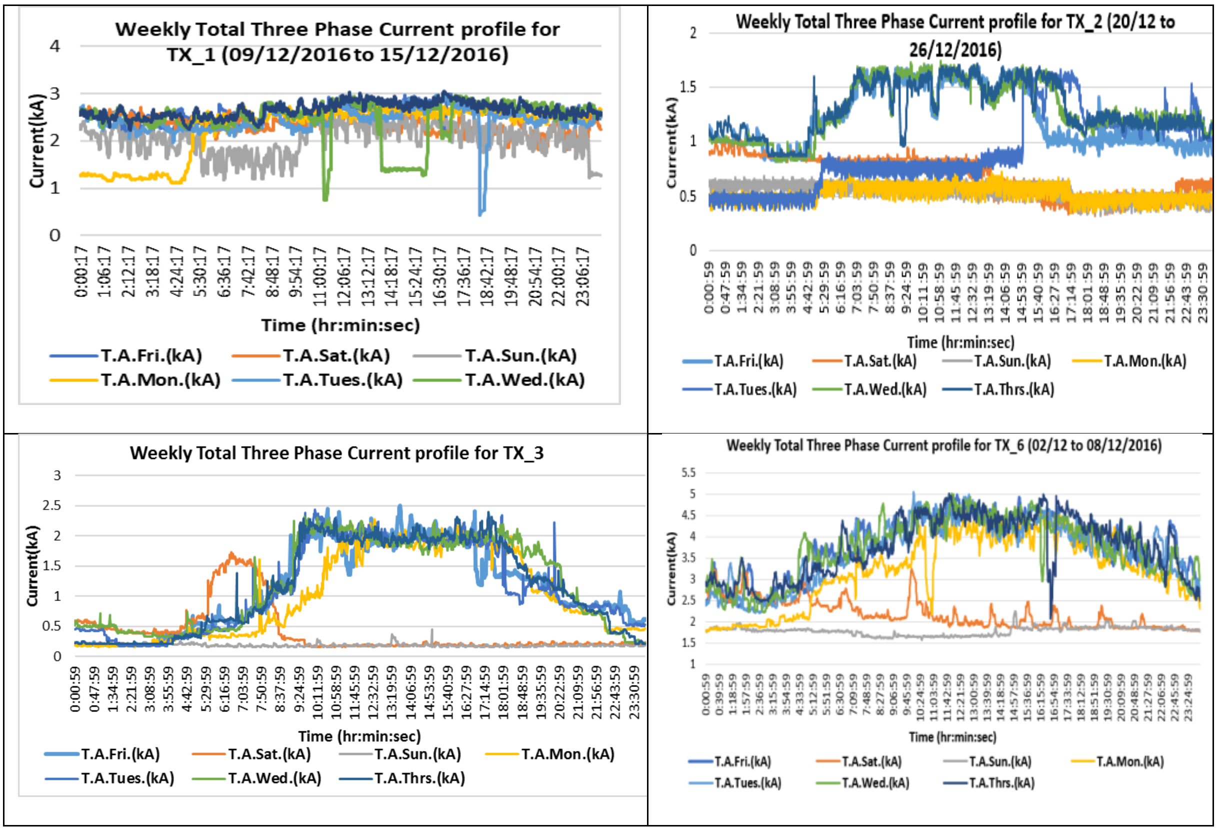


Figure 7 – Weekly current profiles for refrigeration (TX1), kill floor (TX2), by-products (TX3) and general distribution (TX6) feeder transformers

It can be seen in Figure 7 that general distribution transformer (TX_6) is more heavily loaded than the other three transformers. During weekdays (Monday to Friday), kill floor (TX_2), by products (TX_3) and TX_6 have almost similar consumption trends with a significant rise during the day, corresponding to the start and end of the slaughter and boning shifts, returning to a lower overnight baseload. It should be noted that TX2 was measured over the Christmas period, and so there are only 3 weekdays when full slaughtering and boning shifts occurred (Wednesday, Thursday and Friday). Refrigeration (TX_1) shows a much flatter energy consumption pattern where current profiles vary from 2 kA to 3 kA throughout the weekdays. On weekend days (Saturday and Sunday) the TX_6 and TX_2 transformers are less loaded as there are no slaughtering activities on the weekends. Because it services the main refrigeration load TX_1 continues to have a significant load over the weekend.

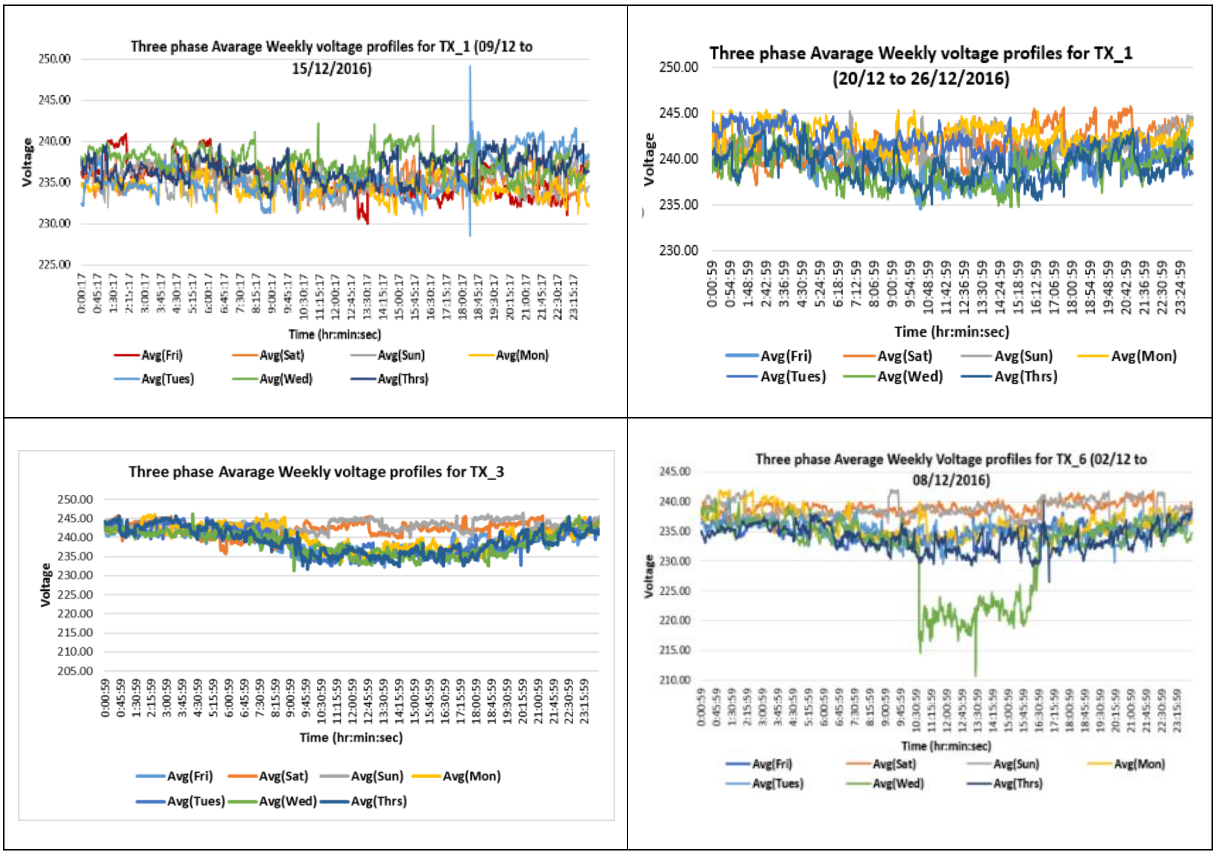


Figure 8 – Weekly average three -phase voltage profiles) for refrigeration (TX1), kill floor (TX2), by-products (TX3) and general distribution (TX6) feeder transformers

In Figure 8, it can be observed that there is a significant voltage drop in TX_6 on Wednesday which remained less than 225V for around approximately 6 hours. This under-voltage may cause an increased possibility of tripping critical loads and power losses. To overcome the problem of a long period of under voltage requires sophisticated equipment, such as a dynamic voltage regulator/optimiser with integrated battery storage. There is an observed transient voltage rise and drop which occurs in TX_1 on Tuesday. The voltage rises close to 250 V. This overvoltage event can cause overheating and may eventually shorten equipment life. In this situation, a voltage optimiser would keep the supply voltage down to optimum levels, which not only offers potential savings on energy but potential reductions in the temperature of the load equipment, therefore giving an increase in the life of the equipment.

Average voltage variations throughout the week for TX_6 and TX_1 are seen to vary between 233 V and 240 V. Voltage levels in TX_2 however show significantly higher values than the other two transformers, ranging from 238 V to 245 V. It is not clear whether this reflects normal operations or is because TX2 was measured close to and during the Christmas break, when the surrounding sites may not have been operating at normal loads, and therefore the voltage on the feeder line was higher.

The deviation from the average supply voltage and weekly voltage frequencies are also presented for each of these transformers (typical refrigeration in Figure 9 & 10, kill floor in Figure 11 & 12, by-products in 13 & 14, and general distribution in 15 & 16). It shows that voltage levels between 236 V and 238 V are dominant for general distribution (Figure 16) and refrigeration (Figure 10). Voltage levels of 240 V and above are less dominant for these two transformers whereas voltage levels of 240 V and above are more dominant, for kill floor (Figure 12) and by-products (Figure 14). The minimum observed voltage for kill floor is 236 V.

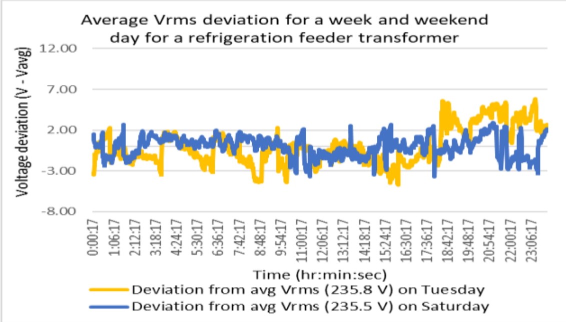


Figure 9: Deviation from the average VRMS on a week and weekend day for a transformer with a mostly refrigeration load at a medium-sized abattoir

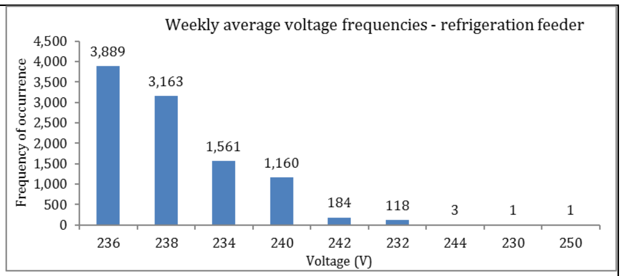


Figure 10: Frequency of average line to neutral voltage over a week for a transformer with a refrigeration load at a medium-sized abattoir

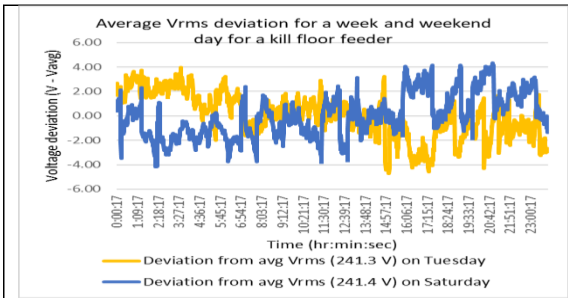


Figure 11: Deviation from the average V_{RMS} on a week and weekend day for a transformer with a kill floor load at a medium-sized abattoir

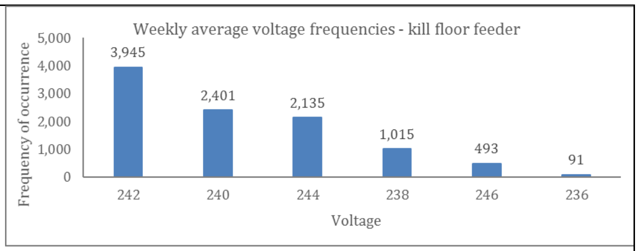
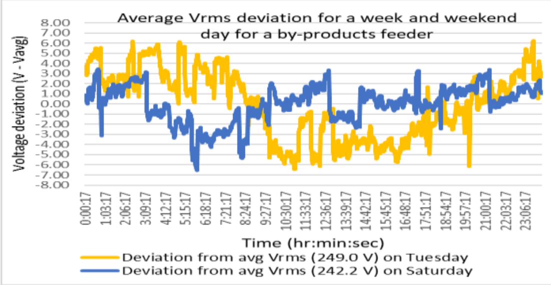


Figure 12: Frequency of average line to neutral voltage over a week for a transformer with a kill floor load at a medium-sized abattoir



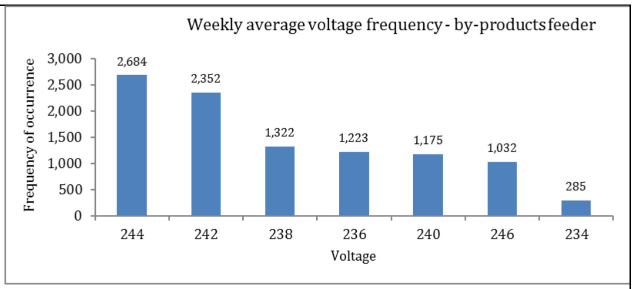
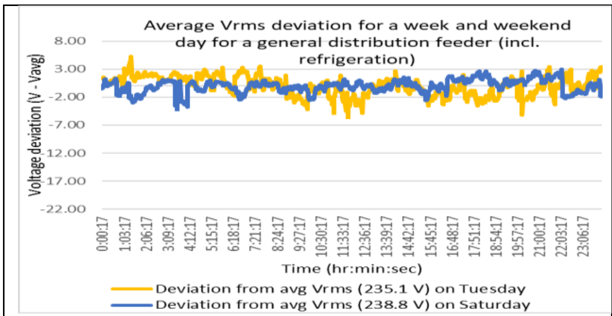


Figure 13: Deviation from the average VRMS on a week and weekend day for a transformer with a by-products load at a medium-sized abattoir

Figure 14: Frequency of average line to neutral voltage over a week for a transformer with a by-products load at a medium-sized abattoir



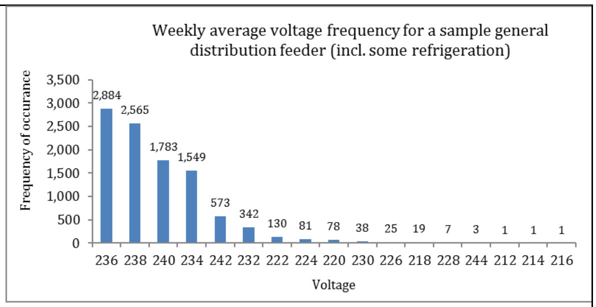


Figure 15: Deviation from the average VRMS on a week and weekend day for a transformer with a general distribution load (including some refrigeration) at a medium-sized abattoir

Figure 16: Frequency of average line to neutral voltage over a week for a transformer with a general distribution load (including some refrigeration) at a medium-sized abattoir

5.2.2.3 Power Factor and Harmonics Analysis

The ratio between real power and apparent power in a circuit is called the power factor (p.f.) which is a practical measure of the efficiency of a power distribution system. A p.f. less than 1.0 causes some additional energy loss as more current is required and the lower the power factor, the higher the apparent power drawn from the distribution network. For most commercial power supply contracts any period with a p.f. below a specified limit usually results in a p.f. surcharge. For instance, Ergon Energy in Queensland requires a customer to ensure that the p.f. of any electrical installation measured at the customer's terminals is not less than 0.8 lagging for installations supplied at low voltages (< 1kV) [19].

Power factor was measured for each of the main transformers over a one-week period. It was seen that the average p.f. of the kill floor transformer (TX_2) was 0.85 and remains mostly constant throughout the day. On the other hand, the average p.f. of the general distribution transformer (TX_6) is around 0.85 but when the loading is low, especially early in the morning, the p.f. at the transformer is less than 0.8. One of the reasons for this low p.f. is that the connected motors' loadings are significantly less than during daytime operational periods. On Saturday the p.f. profiles of both TX_2 and TX_6 are less than 0.8 for most of the time and as a result the cost of electricity will be higher. Considering the lower power factors, these transformers would be optimal for the application of VO, as by reducing kVAr, the VO can also improve the p.f. to some extent.

A poor power factor can also be improved by adding power factor correction capacitors to the plant's distribution system. Correction capacitors provide needed reactive power (kVAr) to the load. Distribution system losses are also reduced through power factor correction by reducing the total load current in the system. Some VO device suppliers [20] claim that their equipment can also improve the power factor (by 5% to 10%) and phase voltage imbalance (by up to 20%), which all contribute to reducing energy losses and enhance system efficiency [21]. However, these claims have not been independently verified. In some field trials [22 - 23] it was identified that the reduction of voltage reduces the active and reactive power consumption to some extent, depending on the load types, and therefore improves the power factor.

Total harmonic distortion (THD) is related to either current harmonics or voltage harmonics, and is defined as the ratio of the sum of the power of all harmonic components to the power of the fundamental frequency. The THD measurement of the refrigeration (TX_1) and general distribution (TX_6) transformers during typical weekdays at the case study site showed that the THD values are within the recommended limits of 8% [24] on the low voltage side. TX_1 has higher THD than TX_6 due to the refrigeration loads. The measurements also showed that the level of total harmonic distortion is quite low on a typical weekend day relative to the weekdays, which is expected as there are less loads on the weekend.

The presence of harmonics in the waveform of the network voltage can be attributed to various causes such as rectifiers, variable speed drives, thyristors, a saturated transformer, etc. If the harmonic power is significant, i.e. total harmonic voltage distortion (THVD) is greater than 7% and total harmonic current distortion (THID) is greater than 40%, this can result in overvoltage and overloads, which may lead to the failure of the capacitors, circuit breakers, contactors etc. Harmonic power losses can be reduced through the use of reactors or harmonic filters. In some voltage optimiser technologies [21], the harmonic filtration is integrated (e.g. in the Power Perfector VO), reducing overall THD.

5.2.3 Data Collection and Analysis for Case Study Site 2

5.2.3.1 Data Collection

The data was collected at the Case Study 2 site using a Powermonic PM45 [25] and included voltage and current across three phases. The data was collected from the incoming on-site transformer that feeds the main switchboard. It was collected for the purpose of assessing the feasibility of developing a utility-scale, solar photovoltaic system that would sit adjacent to the abattoir site, and provide electricity in parallel to the grid. Figure 17 shows the voltage and current profile over a three-day period.

Figure 17 – Voltage (top) and Current (bottom) profile over three-day period at Case Study Site 1

5.2.3.2 Load and Voltage Profiles

Voltage deviation from the average supply voltage for the whole site in Queensland is shown in Figure 18, which shows very similar weekday profiles. High voltages are observed in the network from midnight to early morning and sunset to midnight due to less loading, while lower voltages are observed during day time due to high loading in the abattoir and surrounding area. On the other hand, the weekend profile fluctuates with time due to the number of connected loads in the network. Figure 19 shows the average apparent power and voltage deviations on Monday, where lower voltages are observed with the increase of load demand and higher voltage with the decrease of load demand in the abattoir. From the frequency distribution, as shown in Figure 20, it is seen that 41% of the time site voltages are more than the nominal voltage of 240V and, hence, more energy and costs savings will be possible from this site through the use of VO technology.

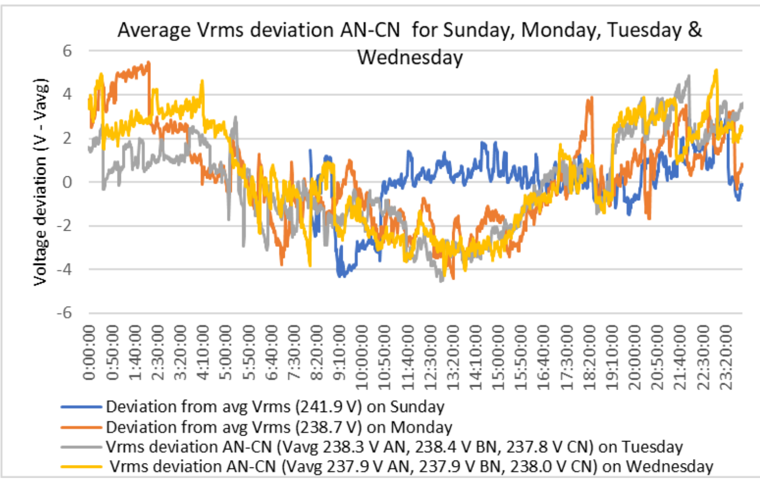


Figure 18: Deviation from average Vrms for Sunday, Monday, Tuesday and Wednesday

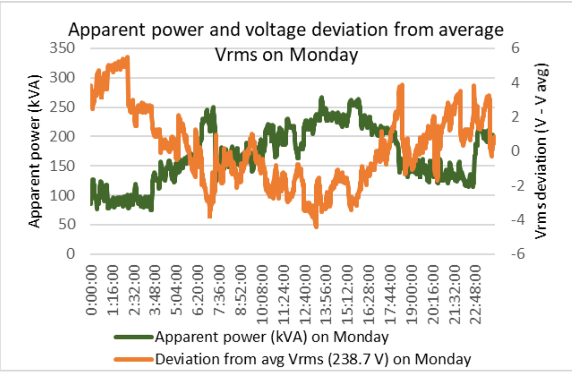


Figure 19: Deviation from average Vrms and power demand on a weekday

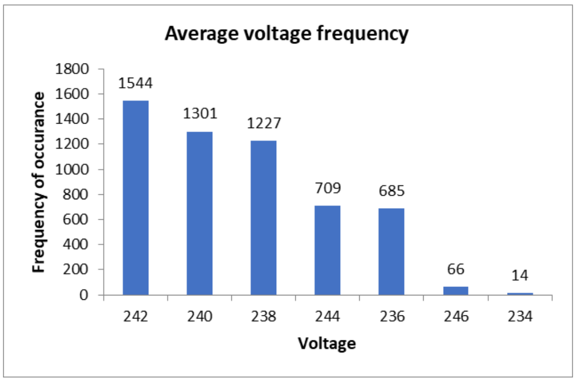


Figure 20: Average voltage frequency for a transformer connected to the main load

5.3 Techno-Economic Analysis

To determine whether voltage optimisation can be implemented, and whether it is economically worthwhile for red meat processing sites the study has undertaken a techno-economic analysis of the use of voltage optimization. A sensitivity analysis around key factors including price of electricity, facility/electrical feeder size (electricity consumption) and load type, supply voltage and optimizer type (dynamic or static) were conducted and identified the energy savings and payback period with various sensitivity variables to evaluate the effectiveness and usefulness of voltage optimisation technology for abattoirs.

5.3.1 Standard sized abattoir for analysis

The energy savings and simple payback periods identified, unless stated otherwise, are based on a typical medium-sized abattoir[1] with an average of 600 head kill/day, operating 5 days per week (250 days per year) with an average supply voltage of 240 V (per phase) and an electricity tariff of AUD$0.15/kWh (including supply charges). Four main transformers are considered for the load, three of which are rated at 1 MVA supplying the refrigeration, kill floor, and by-products feeders and a 1.5 MVA general distribution feeder (which also includes some refrigeration loads). The feeders with refrigeration loads are considered to contain a high proportion of variable speed drives (VSDs) on those refrigeration loads, which is common practice now in most abattoirs. The annual electricity consumption of this representative site is approximately 15,800 MWh.

5.3.2 Energy Savings Calculation

As mentioned previously, voltage, current and p.f. data for each phase of the transformer were collected at 1 minute intervals over a seven-day period. These were used to ascertain the potential energy savings for each of the VO voltage level settings when considering the application of dynamic VO[2].

[1] This is based on site visits and data collection from two abattoirs, one in Western Australia and one in Queensland, with kill rates of ~600 head per day. These are considered typical medium sized abattoirs.
[2] The details of how the savings were calculated are given in detail in Shafiullah et al., "Voltage Optimisation Technology for an Australian Abattoir—A Techno-Economic Evaluation:" Energies 2017, 10(11), 1764. Available from http://www.mdpi.com/1996-1073/10/11/1764/pdf.

5.3.3 Indicative prices for voltage optimisation technologies

Error! Reference source not found. Table 3 and **Error! Reference source not found.**4 provide a summary of the different sizes and indicative costs of dynamic and fixed voltage optimisation technologies, respectively[3]. Costs are given per kVA as well as the total capital cost, considering the installation costs but not the transportation costs as these vary significantly depending on the supplier and location of the installation. These prices can only be viewed as indicative and therefore voltage optimisation technology suppliers should be contacted directly for more accurate prices in a particular circumstance.

Table 3: Indicative prices and installation costs of dynamic voltage optimisation technologies [26 - 27]

Rated power (kVA)	Average price (AUD/kVA)	Average cost (incl. installation) (AUD)	Minimum cost (incl. installation) (AUD)	Maximum cost (incl. installation) (AUD)
250	145	36,250	24,100	53,300
300	134	40,200	26,700	59,100
500	196	97,600	64,800	143,500
630	189.5	144,000	95,650	211,700
800	168.5	135,000	89,650	198,500
1,000	164.5	164,400	109,200	241,700
1,250	149.5	186,800	124,050	274,550
1,500	212.5	318,700	211,700	468,5600
1,600	157.5	251,400	167,000	369,600
2,000	141.5	283,300	188,200	416,550
2,500	126	315,300	209,450	463,550
3,000	157.5	472,450	313,850	69,450
3,200	105.5	337,850	224,450	496,700
4,000	101.5	406,800	270,200	598,000

Table 4: Indicative prices and installation costs of fixed voltage optimisation technologies [26 - 27]

Rated power (kVA)	Average price (AUD/kVA)	Average cost (incl. installation) (AUD)
25	150	3,740
135	166	22,400
500	153	76,450
1,000	126	125,800
1,500	114.5	171,650
2,000	106.5	213,100
3,000	103.5	311,150

5.3.4 Energy Savings Analysis

From the data analysis for case study site one, it can be identified that on weekdays and weekends the average voltage levels of TX_6 and TX_1 are 236 V and 238 V, respectively, which are below the 240 V prescribed by the standard. In TX_2, the average voltage level is 240 V. As stated earlier, energy savings from VO technology ultimately depend on the voltage levels and the type of equipment. The higher the voltage levels are, the more energy savings that can be obtained and the shorter the financial pay back periods are.

There are six voltage steps i.e. 240 V, 237.5 V, 235 V, 232.5 V, 230 V and 220 V, which were used in this study as the basis for VO voltage settings to analyse the potential energy savings. These voltage steps

[3] Based on general prices provided by voltage optimiser providers and online prices.

are related to the tap settings of a typical voltage optimiser. For example, the Powerstar VO has 5 tapings, with 2.5 V between each tap [28]. To avoid the low voltage impacts on the equipment such as over-current, malfunction and damage, these voltage levels are limited within ±10% of the nominal 240 V. According to the Australian Standard, individual equipment must operate within ±10% of nominal voltage [29].

The annual energy savings and simple payback period for VO units installed at typical refrigeration, kill floor, and by-product feeder transformers as well as for the whole site (VO units installed on all main transformers) in a medium-sized abattoir (considering VSDs in loads) is given in Figure 21, using a VO set voltage of 220V with a supply voltage of 240 V. Applying voltage optimisation at the refrigeration feeder transformer provides the largest energy savings and shortest payback period compared to the two other types of transformers, even though this transformer contains the highest number of VSDs. Installing voltage optimisation for all the main transformers at a medium sized abattoir also provides a shorter payback period compared to installing voltage optimisation units at the kill floor or by-products feeder transformers only. This suggests that the analysis of the benefits of VO at a site should be undertaken at both whole of site and individual transformer level.

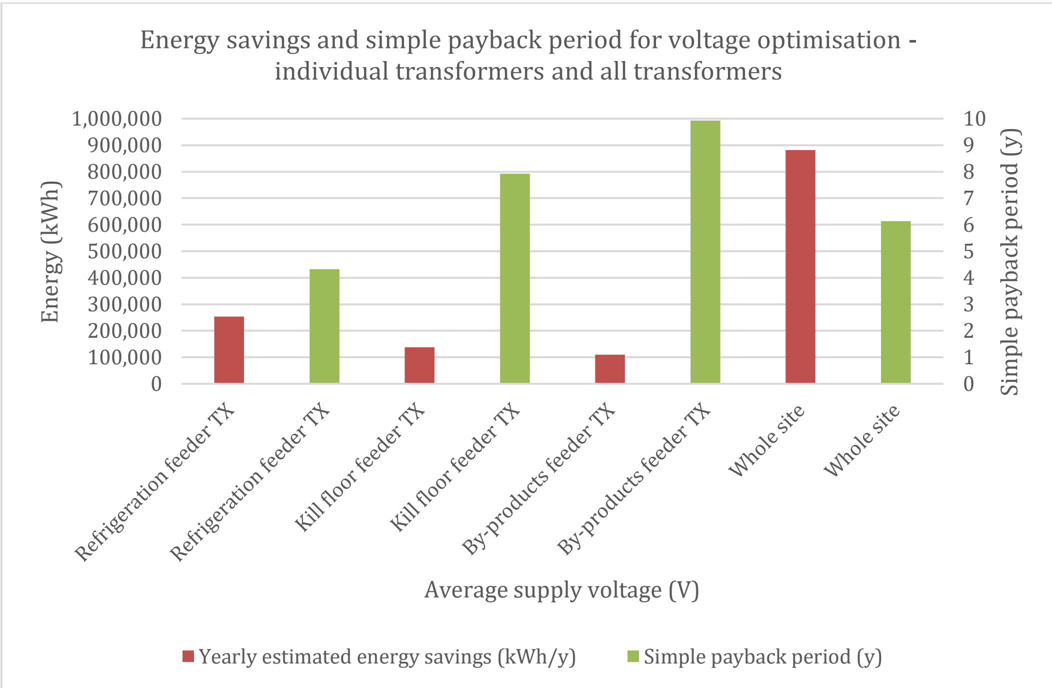


Figure 21: Annual energy savings and simple payback period for voltage optimisation units installed at refrigeration, kill floor, and by-products feeder transformers (1 MVA units) as well as at the whole site

The energy savings and simple payback periods of installing voltage optimisation with a set voltage of 220V at a medium sized abattoir is given in Figure 22, where the effect of VSDs in the load is not considered, and Figure 23, where the effect of VSDs on voltage optimisation is considered. Based on the types of VSDs typically used the energy savings from voltage optimisation applied loads with VSDs is estimated to be 35% less than loads without VSDs in this analysis. On the other hand, Figure 24 and Figure 25 represents the energy savings and payback period for a single transformer supplying the main load (1 MVA transformer) at the case study abattoir in Queensland with and without VSD respectively. This shows that whilst the use of VO is more effective on transformers or sites without VSD's there are still energy and cost savings to be made for sites, and individual transformers with VSDs. Again, it is important to undertake a detailed analysis to determine the suitability of VO at the whole of site and individual transformer level. For sites without VSD's on suitable motors a detailed analysis of the benefits of installing VSD's, with and without installing VO should be undertaken.

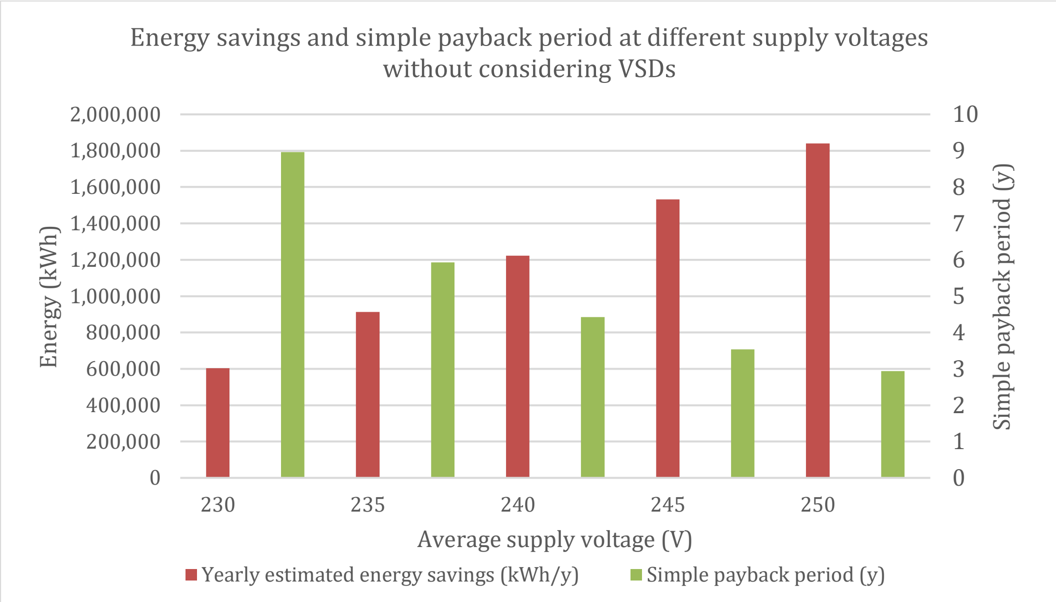


Figure 22: Annual energy savings and simple payback period when applying dynamic voltage optimisation (3 x 1 MVA and a 1.5 MVA unit) with a set voltage of 220V installed at a medium-sized abattoir without considering the effect of VSDs on the load for a range of supply voltages

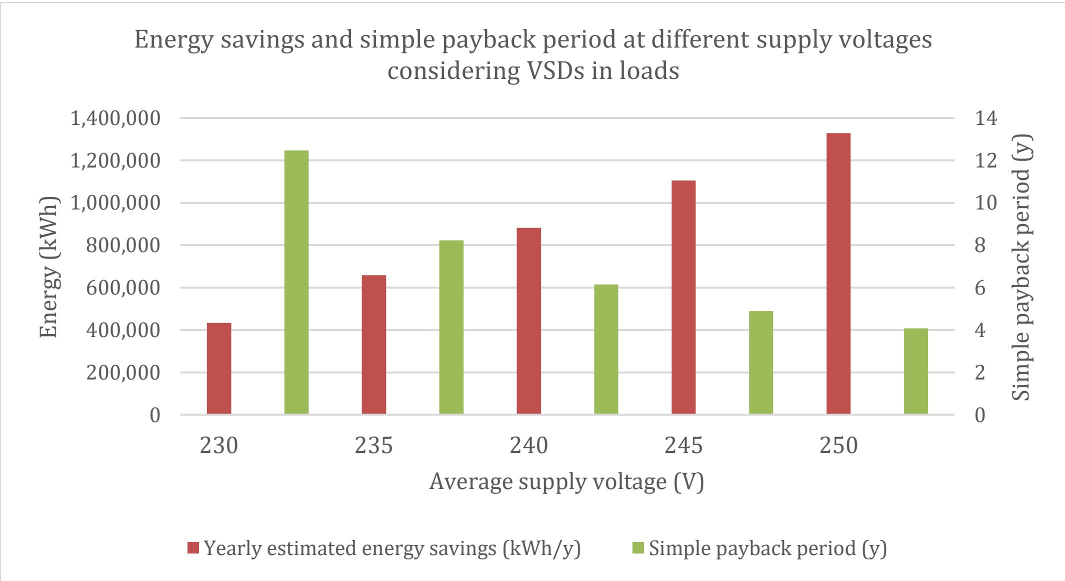


Figure 23: Annual energy savings and simple payback period when applying dynamic voltage optimisation (3 x 1 MVA and a 1.5 MVA unit) with a set voltage of 220V installed at a medium-sized abattoir with consideration of the effect of VSDs on the loads for a range of supply voltages

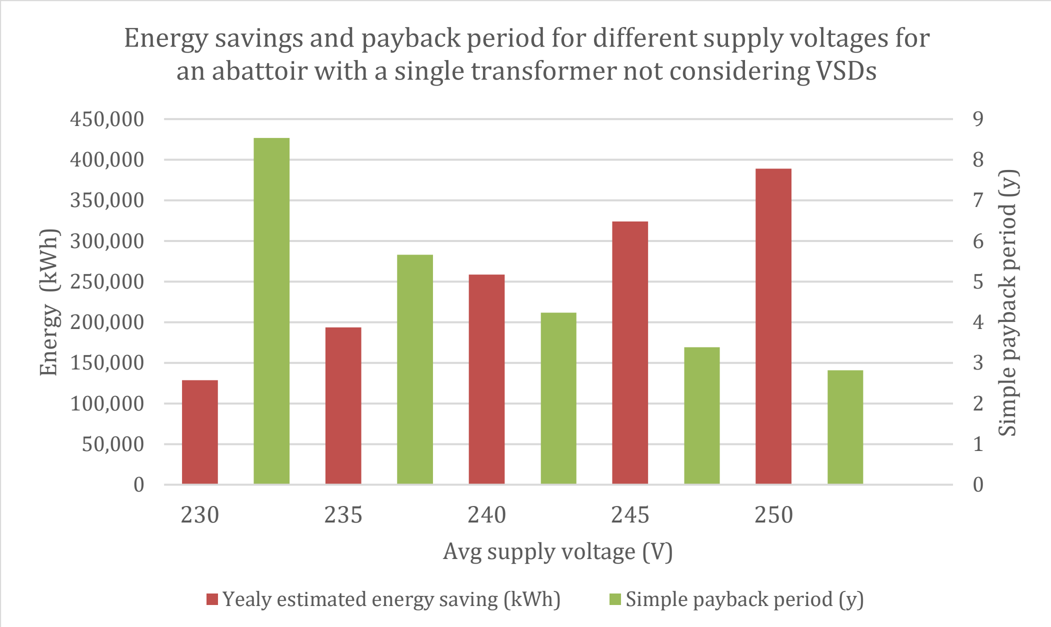


Figure 24: Annual energy savings and simple payback period when applying dynamic voltage optimisation (1 MVA unit) with a set voltage of 220V installed at an abattoir with a single transformer supplying the main load without considering the effect of VSDs on the load for a range of supply voltages

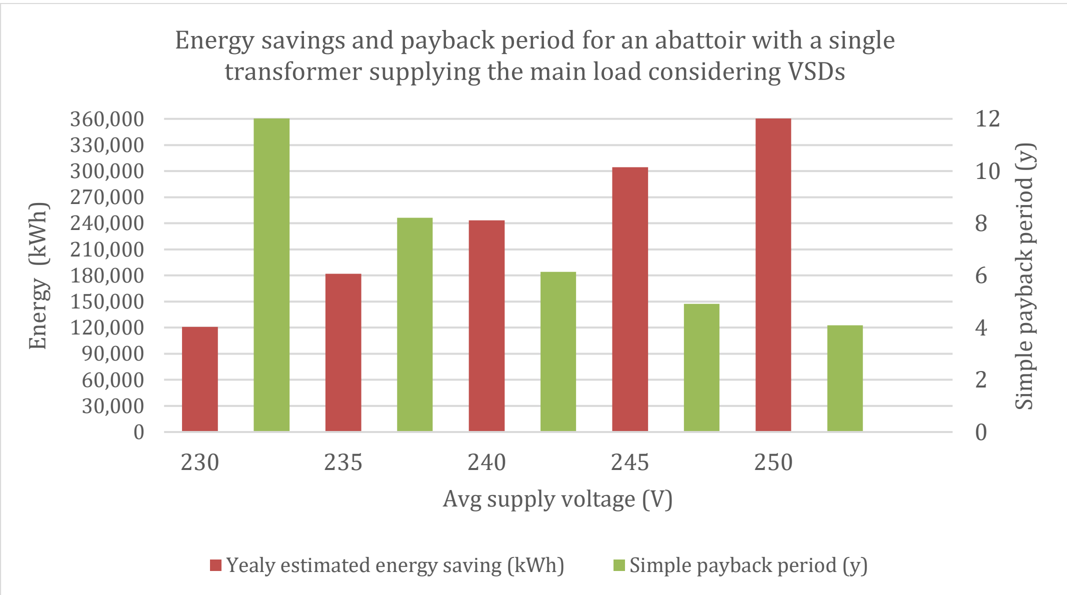
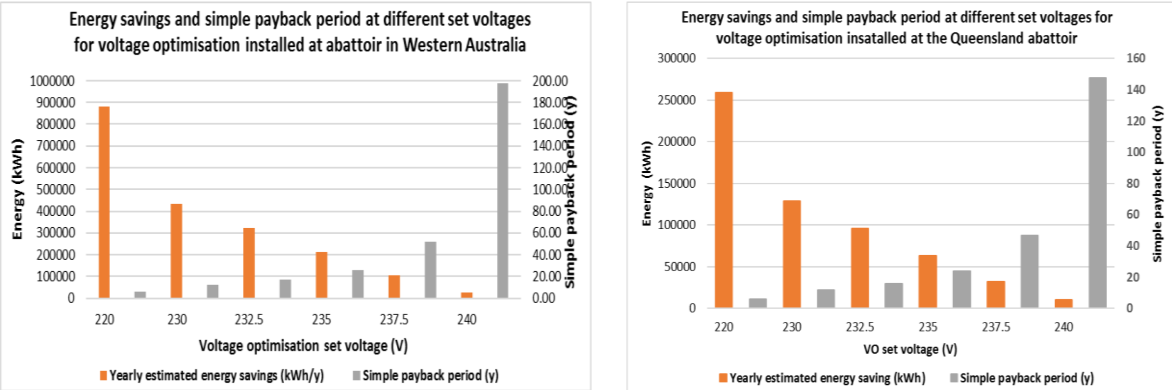


Figure 25: Annual energy savings and simple payback period when applying dynamic voltage optimisation (1 MVA unit) with a set voltage of 220V installed at an abattoir with a single transformer supplying the main load with consideration of the effect of VSDs on the load for a range of supply voltages

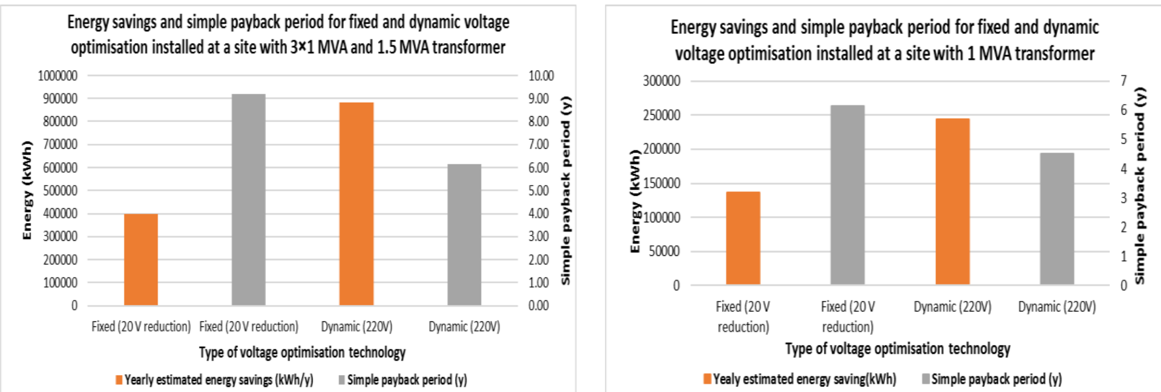
Energy savings and simple payback period for the abattoirs at WA and QLD are shown in Figure 26a and 26b, respectively, with different VO set voltages for a supply voltage of 240V. From the figures, it is evident, as expected, that the highest energy savings and the lowest payback period can be achieved with a VO set voltage of 220 V. Conversely, the lowest energy savings and the highest payback period is for a VO set voltage of 240 V.



(a) (b)

Figure 26: Total site energy savings for different VO set voltages when the supply voltage is 240 V for abattoir in (a) WA and (b) QLD

The energy savings and payback period for 3 x 1 MVA and a 1.5 MVA unit are shown in Figure 27a comparing the introduction of fixed and dynamic voltage optimisation technology at the abattoir in WA, while Figure 27b shows the energy savings and payback period for a 1 MVA unit at the abattoir in QLD. This shows that despite their initial higher capital cost it is usually more cost effective to install dynamic voltage optimisers than fixed voltage optimisers.



(a) (b)

Figure 27: Annual energy savings and simple payback period when applying fixed voltage optimisation and dynamic voltage optimisation with a set voltage of 220V installed at a abattoir in (a) WA and (b) QLD

Figure 28 shows the simple payback period of dynamic voltage optimisation technologies for a range of electricity tariffs for a medium size abattoir (3 x 1 MVA and a 1.5 MVA Unit) with a set voltage of 220V. As would be expected the higher the electricity tariff (especially during on-peak period) the lower the payback period for installing VO. Figure 29 shows the simple payback period of dynamic voltage optimisation technologies at a small (200 head/day), medium (600 head/day), and large abattoir (1200 head/day) with a set voltage of 220 V installed with VO units of 2 MVA (2 x 1 MVA), 4.5 MVA (3 x 1 MVA and a 1.5 MVA), and 9 MVA (2 MVA and 2 x 3.5 MVA), respectively. This analysis suggests that the bigger the site, or transformer the more cost effective the installation of VO will be. As discussed in previosly thouhg this will be dependent on a range of factors and a detailed analysis should be undertaken for each of the main tranformer and the site as a whole.

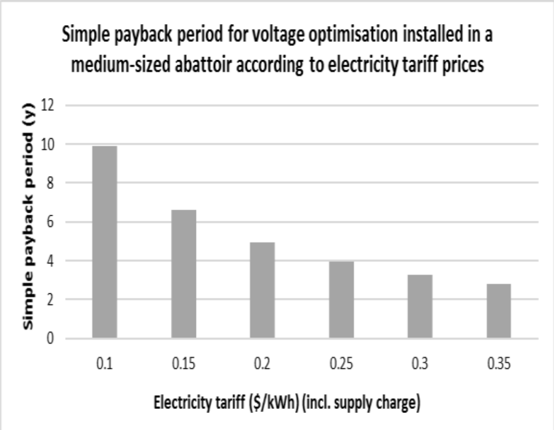


Figure 28: Simple payback period when applying dynamic voltage optimisation with a set voltage of 220V installed at a medium-sized abattoir for a range of electricity tariffs

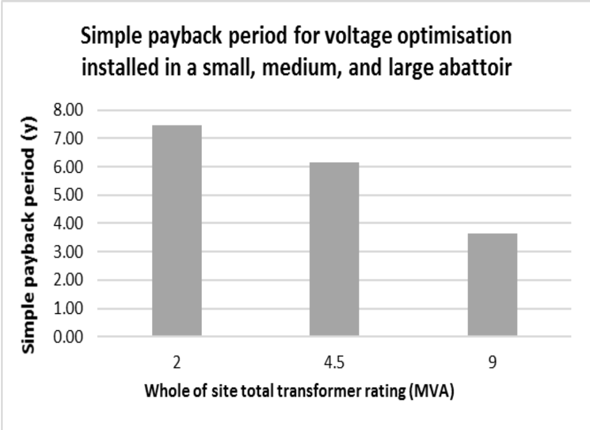


Figure 29: Simple payback period when applying dynamic voltage optimisation with a set voltage of 220V installed at small, medium, and large abattoir with VO units of 2 MVA, 4.5 MVA, and 9 MVA respectively

5.4 Voltage Optimisation Guide

Based on the literature review and analysis of the two case study sites a Voltage Optimisation Guide has been prepared to provide the knowledge about voltage optimisers and how to implement them specifically for the red meat industry. It provides relevant staff within the red meat processing industry with information to:

- Understand the basics of voltage optimization.
- Understand the potential benefits and impacts of voltage optimization for red meat processing facilities; and
- Provide a clear and simple decision-making framework to consider the applicability of voltage optimisation for a site.

The process of understanding and implementing voltage optimisation can be complex. By providing some practical examples, case studies and responses to common questions, the guide can be used to provide direction and justification for further investment (e.g. performing a detailed feasibility assessment).

In most cases detailed investigations will be required to be performed by suitably qualified specialists (either within, or outside of the site), or systems suppliers. These investigations can typically incur time, cost and effort, so it is important to be confident in decision-making that voltage optimisation is a good fit for the site prior to embarking on a detailed feasibility assessment. The guide is designed to assist in doing this initial analysis.

The guide has been separated into two sections; a background to voltage optimisation and a detailed decision-making framework/guide. Initially, general voltage management concepts that are required to make an informed decision regarding voltage optimisation are presented in the guide. This part of the guide also includes a voltage sensitivity checklist that can help to determine if your site's equipment is suitable for voltage optimisation. Additionally, the guide outlines alternatives to voltage optimisation that may be considered for your site. Overall, the first section will provide users with information regarding three key focus areas as shown in Figure 30.

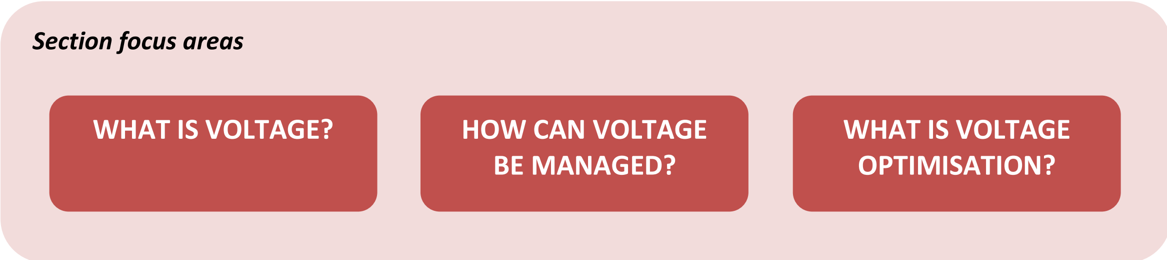


Figure 30: Voltage management overview

Then, in the second section a step-by-step decision-making process for a voltage optimisation investment opportunity is presented. The decision-making process will facilitate site staff in deciding what the benefits and impacts of voltage optimisation may be at their particular site. The flow chart shown in Figure 31 outlines the active process that site staff should undertake in determining the suitability of voltage optimisation at their site. A more detailed description of each of the various steps, with examples, is provided in the guide.

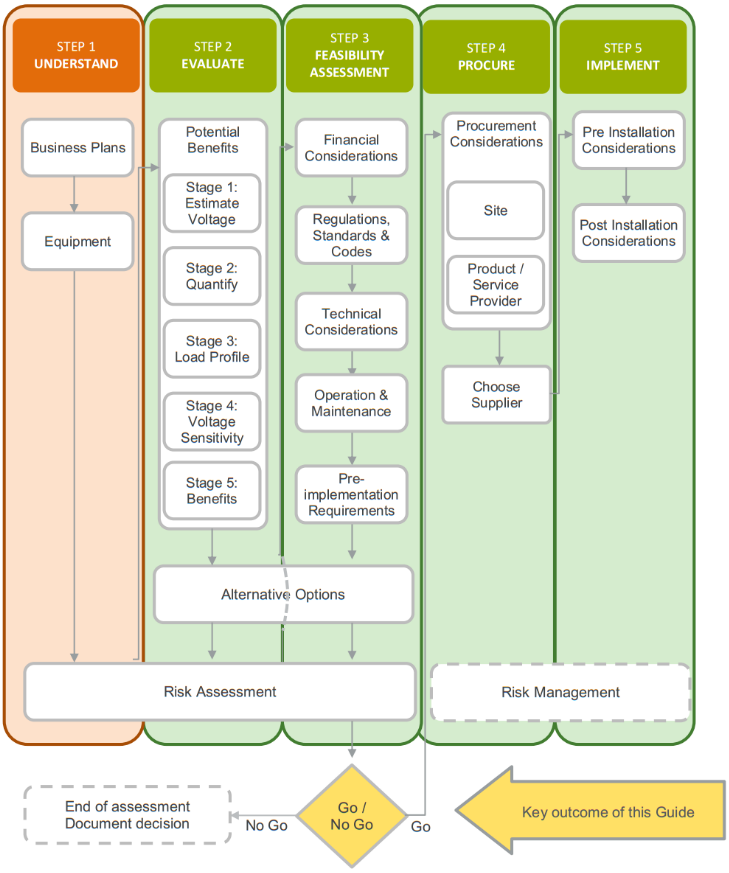


Figure 31: Decision-making framework

Different types of VO techniques and technologies are currently available throughout the world. However, to select a VO technology for an individual site requires a site-specific analysis, which considers the future plan/strategies of the company, types of equipment used and their sensitivity to changes in voltage, load profiles, current energy initiatives, future upgradation, and most importantly the techno-economic benefit of VO installation. The decision-making process presented in the guide is expected to assist in identifying the business drivers as well as the financial viability of voltage optimisation, based on the technical and economic benefits of VO. The key issues that need to be addressed in developing a business plan are shown in Table 5.

Table 5: Business plan considerations

Element	Key Considerations
Business drivers	Business drivers behind considering voltage optimisation (e.g. costs reductions, energy savings). Financial expectations or hurdles (e.g. payback period, Return on Investment).
Site plans / strategies	The current situation of your site (e.g. owned or leased premises). The medium- and long-term strategy (e.g. life of business). Planned activities (e.g. upgrades, expansions, developments, decommissioning). Foreseen changes to operations and productivity.
Energy consumption / management	Current and future energy management / energy efficiency activities. Potential power quality issues on site (e.g. overvoltage, voltage variations). Potential / expected benefits of voltage optimisation (this can be qualitative). Alignment of voltage optimisation to other activities at your site.
General operations and maintenance considerations	Current maintenance and replacement frequency (including associated costs). Known issues associated with your site's electrical infrastructure.

The decision-making guide is supported by practical examples and case studies to support a thorough understanding on whether voltage optimisation is feasible for any given site.

6.0 DISCUSSION

In the begining of the project an extensive litearure review was conducted to identify:

- suitable voltage optimizer technologies and producers in the market and recommendations about suitable voltage optimization/stabilization technologies/solutions for particular representative meat processing facilities in Australia.
- comparison of voltage stabilisation with voltage optimization and a discussion of the potential implications for plant and equipment operating at the facility.

The literature survey demonstrated that voltage optimisation technologies have been widely deployed in different types of industries around the world and are still in use deriving benefits for industrial-scale electricity consumers. The main purpose of using VO is to keep the site voltage within an optimum level to reduce energy consumption and greenhouse gas emissions, along with maintaining adequate PQ in the installed site. From critical reviews it is also evident that voltage optimisation technologies are currently used in meat processing industries around the world. However, until now there has been no publically reported installation of VO within the Australian red meat processing industry.

To determine if there is a case for the adoption of voltage optimisation technology for the Australian red meat processing industry a detailed investigation has been undertaken to understand the state of the electricity supply network and the electrical equipment typically used in the industry and its corresponding operating conditions. Through the analysis of collected electricity characteristics (e.g. voltage, current, power factor) and power quality (harmonic distortion and under voltage, overvoltage events) data over time for two case study sites it was found that most sites would be able to save energy with the targeted implementation of voltage optimisation equipment. The analysis for Case Study Site

1 showed that if 230V could be supplied and maintained for one main transformer alone then annual energy and cost savings could potentially be 70,348 kWh. The analysis for Case Study Site 2 showed that maintaining the voltage level at 230V for the site as a whole could potentially save 122,758 kWh annually.

Moreover, a rigorous techno-economic analysis was undertaken to explore the energy savings opportunities with payback period of implementation. The techno-economic analysis has shown that there are no technical reasons why voltage optimisation should not be installed in red meat abattoirs, and there are in fact many advantages to doing so. Apart from the savings in energy these include less stress on electrical equipment and therefore improved lifetimes with less maintenance, as well as (depending on the technology used) improved power factors and less loss due to harmonic distortion. The economic analysis has shown that for a typical mid-sized (600 head a day) abattoir with a supply voltage of 240 volts and an electricity price of $0.15 a kWh installation of a voltage optimizer will have a payback period of between 3 and 6 years, depending on the supply voltage, type of feeder line and number of VSDs installed. Due to their larger electricity consumption, larger abattoirs will have a lower payback period, as will the use of voltage optimisers on individual large electricity feeder lines, such as refrigeration, compared to the whole site. The use of dynamic voltage optimization is more economically favorable than using voltage reduction. Due to the variation in technologies in the marketplace, and the individual electrical profile of each site, it is important that abattoirs undertake a detailed feasibility analysis before deciding to install a voltage optimizer.

The final outcome of the proposed project is the Voltage Optimisation (VO) Guide. The VO guide, which is tailored for use by red meat processors, will directly inform site staff on the decision process for, and likely outcomes from, the implementation of voltage optimization. This coupled with the short snapshot, disseminated via the AMPC website, will lead to dissemination of the outcomes of the project to the wider industry.

7.0 CONCLUSIONS/RECOMMENDATIONS

Voltage optimisation technologies have been widely deployed in different types of industries around the world to keep the site voltage within an optimum level that will reduce energy consumption and greenhouse gas emissions, along with maintaining adequate power quality at the site. To determine the suitability of voltage optimisation technology for the Australian red meat processing industry this study has undertaken a techno-economic assessment. Through the analysis of collected electricity characteristics (e.g., voltage, current, active power, and power factor) and power quality (harmonic distortion and under- and overvoltage events) data over time, it was found that most feeders on a typical red meat processing site would be able to save energy and ensure enhanced power quality with the targeted implementation of voltage optimisation equipment.

The techno-economic analysis has shown that there are no technical reasons why voltage optimisers should not be installed in red meat abattoirs, and there are in fact many advantages in doing so. Apart from the savings in energy, these include less stress on electrical equipment and therefore improved lifetimes with less maintenance, as well as (depending on the technology used) improved power factors and less losses due to harmonic distortion. The successful implementation and trialling of voltage optimisation technology at one abattoir could serve as the catalyst for widespread installation at meat processing facilities throughout Australia. This study potentially serves as a catalyst for improved energy consumption, power quality and, therefore, potentially improved returns on equipment life right across the red meat processing industry.

By presenting clear information, with case studies in a Voltage Optimisation Guide red meat processing facilities will be enabled to assess the potential savings, benefits and possible issues from installing a voltage optimiser in their facility. This is expected to increase the potential uptake of voltage optimiser technology in red meat processing plants and lead to significant cost savings in red meat processing plants.

It is anticipated that with the information provided in the project outcomes will:

- Save upfront time and costs.
- Mitigate risk and enable a more targeted assessment by facilities.
- Consider the total cost of ownership.
- Expedite the implementation of the technology; and
- Enable the performance of the procurement process in an efficient manner.

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