Reducing Energy Consumption through Voltage Optimisation: Conservation Voltage Reduction in Household Appliances

A report submitted to the school of engineering and information technology, Murdoch University in partial fulfilment of the requirements for a Bachelor of Engineering Degree.

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DECLERATION OF ORIGINALITY

I, Glenn Hazelden, declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given in the references.

Abstract

With growth in demand for electricity within Australian homes since 1980, the necessity to conserve and reduce overall energy consumption has become evident. Conservation Voltage Reduction is a heavily researched and tested technique, implemented to reduce peak demand and energy consumption in order to counter the growing costs to the consumer and minimize the pollution produced from generating the electricity itself.

By reducing the supply voltage within the lower region of regulatory limits, some common household appliances are able to continue operating as the manufacturer designed, whilst consuming less energy. Through physical testing, utilizing a power meter and variable transformer, it was discovered that constant resistive devices, such as the kettle, provided the greatest reduction in energy consumption, followed by constant current devices such as Microwaves and LED lights. Constant power and energy devices did not provide any increase in efficiency or reduction in energy consumption, due to the nature of the device and feedback control mechanisms.

By implementing Conservation Voltage Reduction, constant resistance and current devices are able to consume less energy, and when adopted on a large scale by thousands of homes, a quantifiable reduction in energy; hence a reduced consumption of fossil fuels can be obtained.

Acknowledgements

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Background

Since 1980 the population of Australia has grown 59.88% from 14,692,000 to 23,490,736 million people at the end of 2014 [1], Figure 1. As a result, the demand for electrical energy has increased from 5,915 kWh per capita in 1980 to 10,398kWh in 2015, a staggering 75.79% [2], Figure 2. With the demand for electrical energy having increased significantly since 1980, the necessity to conserve and reduce overall power consumption is becoming increasingly important to maintain a healthier planet.

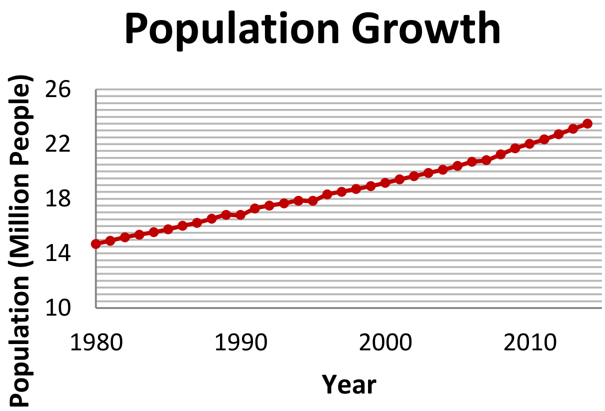

Figure 1 - Population Growth [1]

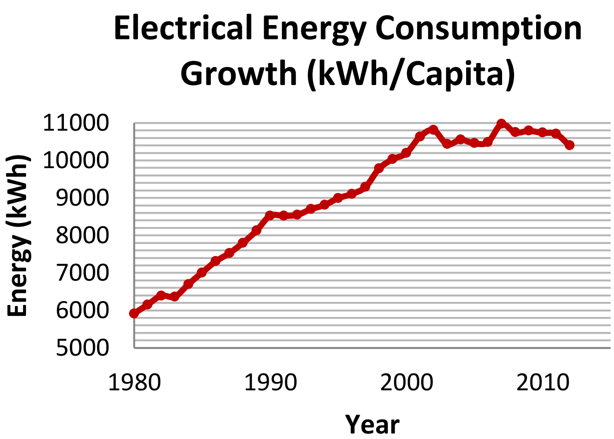

Figure 2 - Electrical Energy Consumption Growth [2]

Electrical energy is mainly produced through the consumption of fossil fuels. As fuels are burnt by-products such as carbon dioxide are released into the atmosphere. Greenhouse gas emissions within Australia included 540 million tonnes of emitted carbon dioxide in 2010, of which 36% alone was produced through electricity generation [3], combined with the above, there are additional costs to generate, transmit and distribute electricity.

Many techniques have been researched, tested and implemented, as a means of reducing energy consumption, however one method which stands out with tests dating back as far as 1973 [3] is Conservation Voltage Reduction.

Conservation Voltage Reduction, abbreviated to CVR, is a frequently researched and tested technique which aims to reduce energy consumption by reducing the input voltage to a given load. By reducing the input voltage to the lower region of regulatory limits, various household appliances are believed to be able to remain operating as the manufacturer desired, whilst reducing the energy consumed, potentially increasing the lifespan and reducing overall losses from the device.

During the 1980’s and 1990’s extensive CVR testing had been conducted, which yielded a quantifiable reduction in peak demand, resulting in a measureable increase in energy savings [4]. The work done in “IEEE: The expertise to make smart grid a reality, Conservation Voltage Reduction” [5] shows a comparison between published research papers. This report found that a range of 0.6-0.95% reduction in energy consumption could be measured for a 1% decrease in voltage. One particular study found that within Australia on a common residential circuit, a 2.5% voltage reduction provided a 1% energy saving [4].

A field study implemented in 2010 had the voltage reduced within regulatory limits to three sites, being Smithfiled Police Station, Yarrabah Health Office and Residence and Yungaburra DERM Workshop and Office. Upon finishing the study, it was discovered that the sites exhibited an energy consumption reduction of 5.29%, 6.87% and 13.35% respectively [6]. After the field study had been concluded, personnel on-site during the testing period were asked to complete a survey regarding the operation of appliances during the study. Results from the survey revealed that no noticeable changes in operation of any appliances found on the site were evident [6]. Additionally, data presented in [7] revealed that generally a better CVR factor can generally be obtained from a heavier loaded feeder, similar to that of a residential feeder supplied from a utilities distribution kiosk.

With need to reduce the overall energy consumption within Australia and move towards a more sustainable future, implementing Conservation Voltage Reduction within residential homes could prove to be a viable option. This thesis aims to;

- Determine whether Conservation Voltage Reduction is a viable option to reduce peak demand and energy consumption in a household environment.
- Through measurement and calculation determine, the performance characteristics for common household appliances and calculate their respective Conservation Voltage Reduction factors (CVRf). Determine under what percentage voltage reduction does each device closely resemble original operation, while proving a measurable and worthwhile ideal energy consumption reduction.
- Through modelling, determine if applying a common voltage reduction across all appliance types yields quantifiable results. Additionally, if implementing a small voltage reduction on a large scale residential feeder, yields results worthy of achieving.
- Finally, would implementing Conservation Voltage Reduction result in significant cost savings to the average home owner?

CHAPTER 1. Conservation Voltage Reduction

1.1 Introduction

Conservation Voltage Reduction (CVR), often referred to as voltage optimisation, is used to reduce overall peak demand and energy consumption. Provided appliances are able to maintain operation as designed by the manufacturer, appliances are able to operate with increased efficiency and therefore reduced energy consumption, when the voltage supplied to the customer's home is reduced.

Voltage optimisation can be implemented on both a small scale, within a single household, or a large scale distribution network. Optimisation can be obtained in a variety of way, such as installing voltage regulation equipment on a local switchboard or adjusting the tap settings on a distribution transformer, resulting in a decreased voltage across the entire local network. Previous analysis on small scale sites, although not indicating a dramatic reduction in energy and therefore cost saving, have shown a measurable reduction in energy; however, small scale sites alone fail to provide sufficient reasoning to adopt the technique. Provided the technique were to be implemented on a large scale, for example on an entire estate or suburb, the total energy savings may provide a sufficient reason to consider implementing Conservation Voltage Reduction.

1.2 CVR Factor: Device Efficiency

Device efficiency can be determined using a number of methods. One common method utilised to present these efficiencies is by calculating the CVR factor. Implementing equation 1 provides an accurate means of presenting quantifiable results and shall be utilised within these tests. The Conservation Voltage Reduction factor is calculated by dividing the percentage change in energy consumption by the percentage change in voltage. CVR values can vary significantly based of the operating characteristics of a device. From the equation, a positive CVRf will be achieved when the percentage reduction in energy consumption is greater than the percentage reduction in voltage.

$$CVR_f = \frac{\%\Delta E}{\%\Delta V} \quad [4] \qquad \text{Equation 1}$$

(where E is the energy measured in kWh and V is the AC voltage applied to the device)

Comparing Conservation Voltage Reduction factors between devices, it is desired to obtain a positive value, as large as possible. This represents the greatest energy savings for a given reduction in voltage.

1.3 Regulatory Limits

Within Australia there are a number or governing bodies in charge of providing clean reliable electricity to the consumer, particularly the network operators. Within Western Australia, power is controlled by Western Power, which is overseen by the Economic Regulation Authority under WA government legislation [8] [9]. Western Power in conjunction with the Electricity Act 1945 Section 25(1)(d) and Electricity Industry (Network Quality and Reliability of Supply) Code 2005 [8] [9], states the supply voltage can only vary +/- 6% from the standard 240V single phase supply.

Based on the above regulatory limits, As CVR works only by reducing the voltage, a range of 240V - 225.6V shall be utilized. Where a given appliance does not have a standard implicitly or explicitly relating to the operation, the appliance shall be operated with reduced voltages only as far as not to impair the function or safety of the appliance and those around. Most devices have a small sticker/plaque or marking indicating the frequency, power and operating voltage range. The majority of household appliances will fall well within these limits, however device and personnel safety is imperative.

1.4 Monitoring the Appliances

Appliance operating characteristics shall be measured using the Energy Meter – System 2000 - 0400 as pictured in Figure 3. This power meter enables device operating characteristics such as instantaneous power, current, voltage and energy consumption to be measured accurately for an appliance in an actual household application. All appliances tested are single phase 240V devices, as a result, despite this power meter providing three phase readings, only 'phase A' shall be documented.

Figure 3 – Energy Meter – System 2000 - 0400

1.5 Load Types

First impressions of CVR are deceiving. One may assume, from the resulting equation of both Joule's Law and Ohm's Law, $P = VI$, no increase in efficiency would result from a reduced input voltage. To some degree this is true; however this only applies to loads with constant power, such as converters [3]. Other devices provide a constant current or resistance, therefore providing a linear or quadratic decrease of power respectively, for a voltage reduction. The various household appliances being tested fall into four load categories, constant resistance, constant current, constant power and constant energy.

- Constant-Resistance – devices such as heaters, kettles, incandescent lamps and electric toasters. These appliances provided a quadratic relationship between voltage and power as seen in equation 2 and therefore are expected to provide a Conservation Voltage Reduction Factor, in the range of $CVRf = 2.0$ [3] [11].

$$P = \frac{V^2}{R}$$ Equation 2

- Constant-Current – Typically seen in electronically controlled devices such as the LED lamp and microwave. From equation 3, constant current appliances provide a linear relationship between power and voltage and are expected to produce a reduction factor in the range of $CVRf = 1.0$ [3] [11].

$$P = VI$$ Equation 3

- Constant-Power – Devices falling within this category are switch mode power supplies, computers, TV's etc. As these are constant power devices, from both equations 2 and 3, reduction in energy consumption is expected under reduced voltage conditions, resulting in a reduction factor of $CVRf = 0.0$ [3] [11].

- Constant-Energy – Devices with feedback control loops, such as temperature controlled air conditioning and refrigerators. As per constant power loads, constant energy loads will also remain unaffected by voltage reduction and are expected to result in a reduction factor $CVRf = 0.0$. [3] [11].

From the theory, both constant power and energy loads will not be affected by CVR. As the name suggests, constant power and energy, means the values are fixed and provide no reduction with respect to change in voltage, always resulting in a $CVRf = 0.0$ However, for a complete and thorough analysis, devices within these load categories shall be included within the testing.

It is important to note that some appliances may contain a mixture of the various load categories and may only show a reduction in energy consumption with respect to the load types directly affected by a varying voltage.

This research does not consider the reactive power demand of devices. Reactive power is zero for constant resistive devices such as the incandescent globe, kettle etc, however, appliances such as the fluorescent tube, refrigerator and motor will have a neglected reactive power component.

1.6 Devices Compromises

This thesis refers to the change in a devices designed operation, from original manufacture, to reduced voltage operation, as the 'compromise'. This will be further elaborated.

Energy consumption will not be reduced, without compromising in the operation of the device. With each device, a respective compromise can be established. For example, when reducing the voltage to the incandescent globe, as voltage reduction is implemented, the light intensity produced decreases.

If CVR were to be implemented within households, the 'compromise' in operation must be considered in conjunction with the reduced voltage to be selected. That is, a reduced voltage cannot be implemented should the reduction deem the appliance unsuitable for use. Each appliance presents a compromise which will be individually quantified under each device.

When reducing the voltage and considering each device compromise, provided no discomfort is brought and occupants are happy with the devices operation, the reduction in voltage shall considered fit for application.

1.7 Voltage Adjustment and Testing

To apply and test Conservation Voltage Reduction, the voltage from the laboratory's power outlet must be reduced within the lower region of regulatory limits, 240V-225.6V. Voltage reduction shall be achieved using a variac type Auto-Transformer. Simply, a Variac is a single winding transformer with a variable voltage output as a result of a change in tap position.

Observing Figure 4 below, a circuit diagram showing how the device operates can be seen. The 'Primary Side' refers to the 240V input from the general power outlet (GPO) going into the variac/ transformer windings. On the right side, the arrow indicates variability along the windings/taps and 'Secondary Side', where the power meter and devices shall be connected.

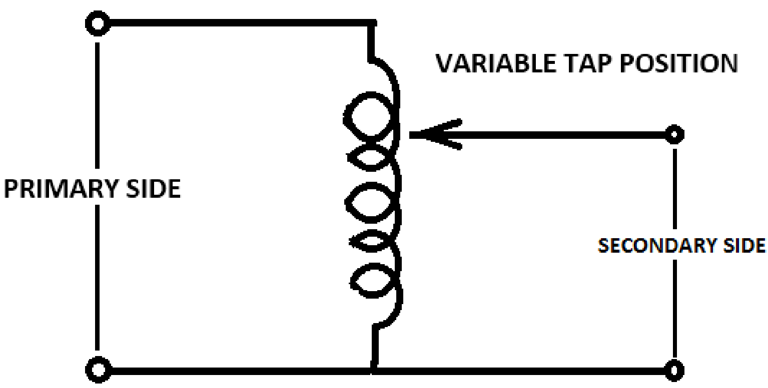

Figure 4 – Auto Transformer / Variac

The voltage shall be varied in 0.5% decrements until the lowest possible voltage, subject to regulatory limits, is achieved. Reducing the voltage in 0.5% decrements results in thirteen physical tests be taken, 0%, 0.5%, 1%, 1.5%....6%. Voltage reduction shall be varied whilst considering each individual appliance manufacturer recommendations. For example, if a given appliance recommends a voltage minimum of 235V, despite the voltage being well within the 6% allowable limit, the manufacturer does not recommend the device operate below this value and testing below this will not be undertaken.

Each appliance shall be tested under the above circumstances, with three individual tests, where the median data shall be selected. Should any of data the obtained during the three tests be significantly different from another test, the device shall be further tested to eliminate error.

1.8 Connection Diagram

Figure 5 below shows the physical connection diagram for the testing equipment. The single phase load is connected to the energy meter system 2000-0400. The meter is then connected to the variable voltage transformer which is connected to the general power outlet located on the wall of the laboratory. The supply has been denoted as single phase by adding the 45° blue line between the power outlet and transformer.

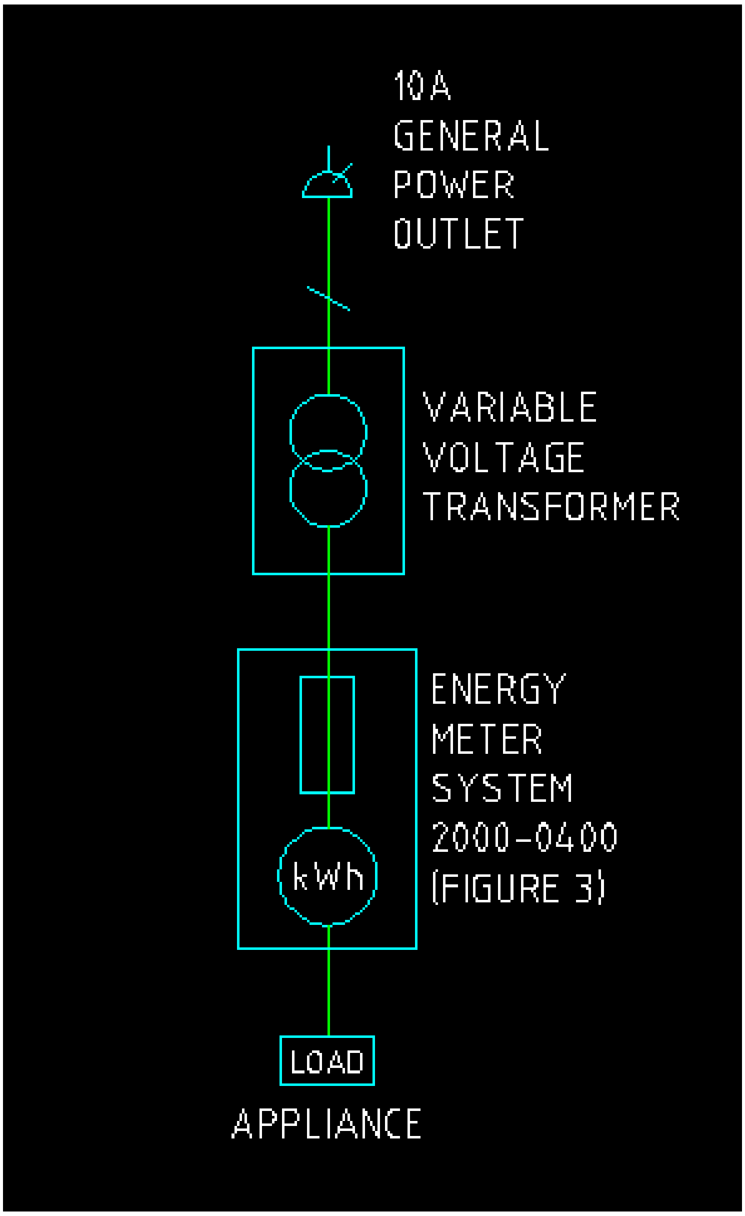

Figure 5 - Connection Diagram

CHAPTER 2. Lighting Appliances

Under this category, three common lighting types seen within modern homes have been explored. Physical testing on Incandescent lamps, Fluorescent tubes and light emitting diodes (LED) have been undertaken to determine the efficiency and operating characteristics under reduced voltage conditions. Physical testing allowed instantaneous power, energy, current, voltage and Light output (LUX) to be measured under reduced voltage conditions (described in 'Voltage Adjustments and Testing'), utilising equation 1 the efficiency CVRf has been calculated.

As the voltage is reduced to lighting appliances, the resulting compromise is the variance in light intensity output. To capture this reduction, the lights were operated within a dark space and the light output measured using a digital lux meter. Ideally the least variance in lux for the greatest reduction in energy consumption is desired.

Standards concerning lighting applications range from AS1680 'Interior and workplace lighting', AS1680.2.1 – AS16802.5 'Circulation spaces and other general area', 'Office and screen-based tasks', 'Educational and training facilities' and 'Industrial tasks and processes'. However, since the measurements and testing are concerned with the common household appliances utilized in a home environment, the above mentioned or any standard concerning lighting levels do not extend to this application.

When considering lighting levels for residential homes it is simply the occupant's decision to select a desired lighting intensity. When LUX is reduced as a result of CVR implementation, provided no discomfort is brought and occupants are satisfied with the lighting levels, the reduction in voltage shall be considered acceptable.

Final efficiency of the lighting appliances shall be determined whilst considering both the Conservation Voltage Reduction factor and the total variation of light output produced from each lighting device independently.

2.1 Incandescent Lamp

Three types of lighting appliances commonly used in the modern household are being tested for efficiency and energy consumption reduction whilst operating at reduced voltage conditions. The first lighting appliance to be tested is the incandescent lamp. As the name suggests, this device produces light through incandescence, a current passes through a filament wire, heating it up to a high temperature producing light. The wire is contained within a glass bulb containing an inert gas to prevent oxidation on the wire [12]. Of the three types of lighting devices being tested, the incandescent lamp is by far the most inefficient lamp. Typically during operation, 90% of power is lost to heat with the remaining 10% producing light [13], hence the decreased usage of this light.

2.1.1 Compromise

As described above, the incandescent lamp produces light from current passing through a fine filament contained within an inert gas filled bulb. To capture the efficiency of the lamp, since the sole purpose of this device is to emit light, it is desired to capture the light output as the voltage is reduced. Provided the lighting application was anything other than a household, for instance a school, commercial building, office etc. Average LUX throughout the space must meet Australian Standards. However, as discussed above Australian Standards does not encompass minimum lighting requirements for residential homes.

2.1.2 Testing Procedure

In order to accurately capture the light intensity (LUX) of the incandescent lamp, the lamp was connected through the power meter and variable transformer, as per Figure 5. Once connected, the lamp was installed within the small enclosure to remove all residual ambient light. Within the enclosure, a light meter was placed 1m from the globe to measure the LUX output. Once switched on, using the power and light meter, instantaneous power, voltage, current, energy and lux were recorded over a 10 minute period for each 13 test voltages. Light output was recorded at the 9 minute mark of each test to allow adequate time for the filament to completely heat.

Further allowing 15 minute cool down period between each voltage test to remove all residual heat left within the globe and testing equipment.

2.1.3 Voltage v. Energy

Observing the voltage v. energy relationship for the incandescent globe shown in Figure 6 below. When operated for 10 minutes at 240V (+/- voltage fluctuations) the incandescent lamp consumed 15.42Wh. With a 3% voltage reduction applied by adjusting the auto transformer, the measured energy consumption was 4.77% lower than at 240V. An energy consumption reduction of 9.18%, (1.42Wh less) was measured, while operating at the lower regulatory limit of 6% (225.6V).

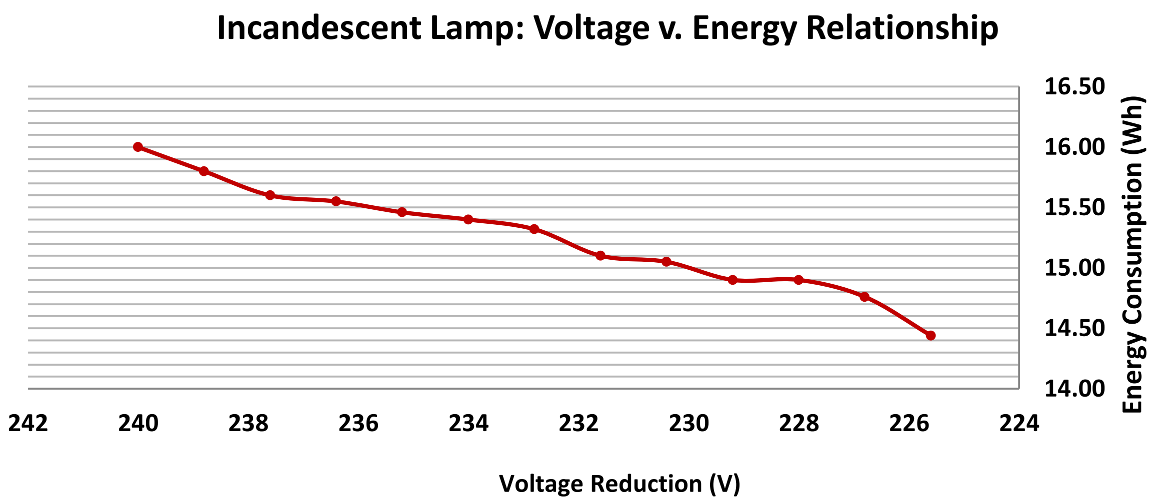

Figure 6 - Incandescent Lamp: Voltage v. Energy Relationship

2.1.4 Voltage v. Power

The reduction in energy seen above is directly related to the decrease in continuous instantaneous power consumption, as illustrated in Figure 7. Operating at 240V the incandescent lamp recorded a power consumption of 92.5W, providing a decreasing trend as the voltage is reduced. At 231.6V a slight increase to 88.1W from 88.09W meeasured at 232.8V. At the lower regulatory limit 225.6V the lamp consumed 84.01W, 9.17% less than the 92.5W at 240V.

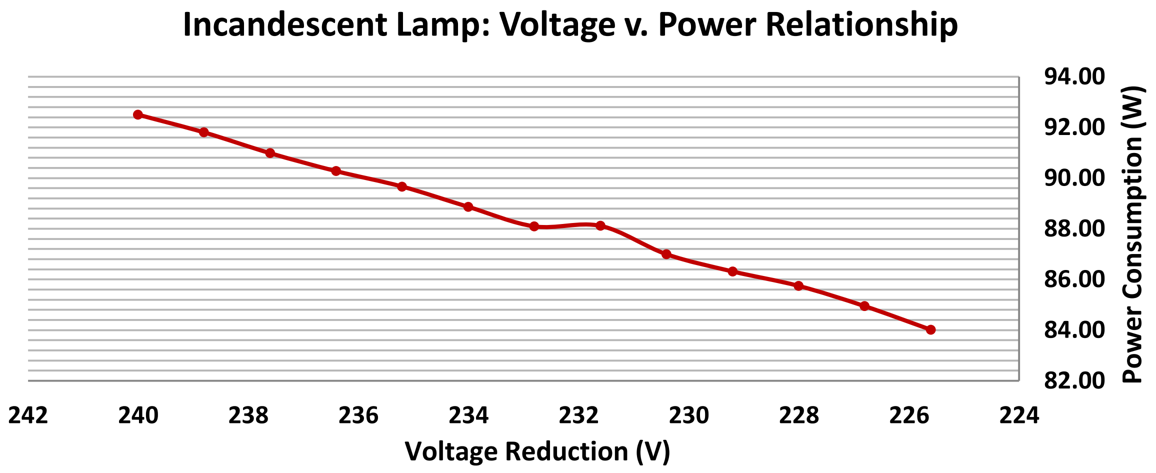

Figure 7 - Incandescent Lamp: Voltage v. Power Relationship

2.1.5 Voltage v. Light Output (LUX)

Observing in Figure 8 below, from a basic understanding of the devices operation, it is understood that as power is reduced, heat and light output decreases. Whilst operating at 240V the incandescent lamp produced a light output of 381LUX. With 3.0% voltage reduction applied the incandescent lamp fell linearly to 339LUX, 11.02% lower than the initial state. At 6.0% reduction or 225.6V the lamp reduced further to 296LUX, 22.31% lower than the initial 240V measurement.

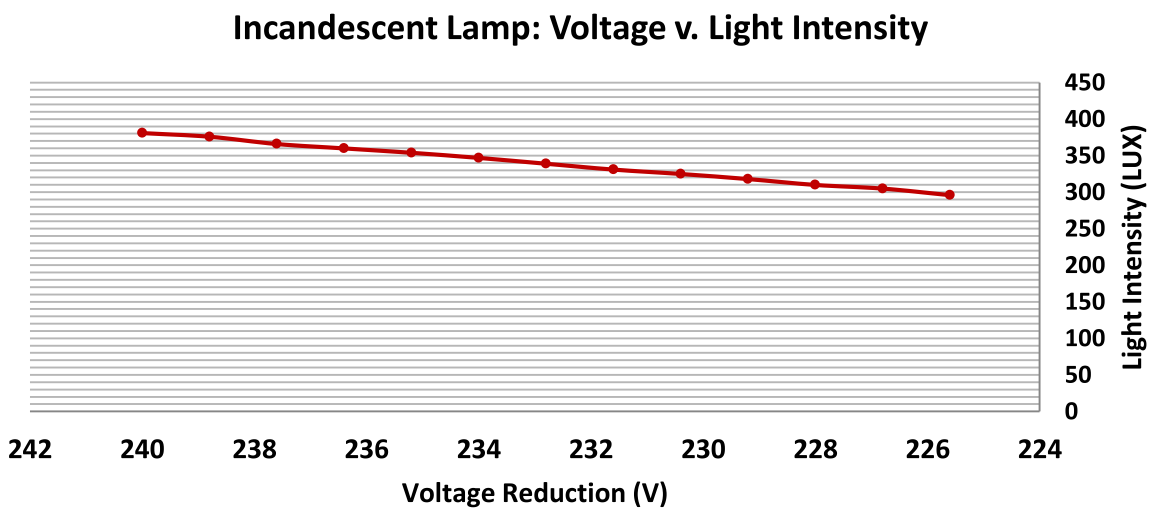

Figure 8 - Incandescent Lamp: Voltage v. Light Intensity

2.1.6 Reduction Factor

The constant resistance, incandescent globes Conservation Voltage Reduction factors for each 13 decrements in voltage can be seen plot in Figure 9. At the first 0.5% voltage drop the globes voltage and energy reduction results in a factor of $CVRf = 1.51$. As the voltage is further reduced, the lowest factor was recorded at 231.6V generating $CVRf = 1.36$. Across the thirteen values this lighting device produced a efficiency factor of $CVRf = 1.52$ with the values varying between 1.36 and 1.64.

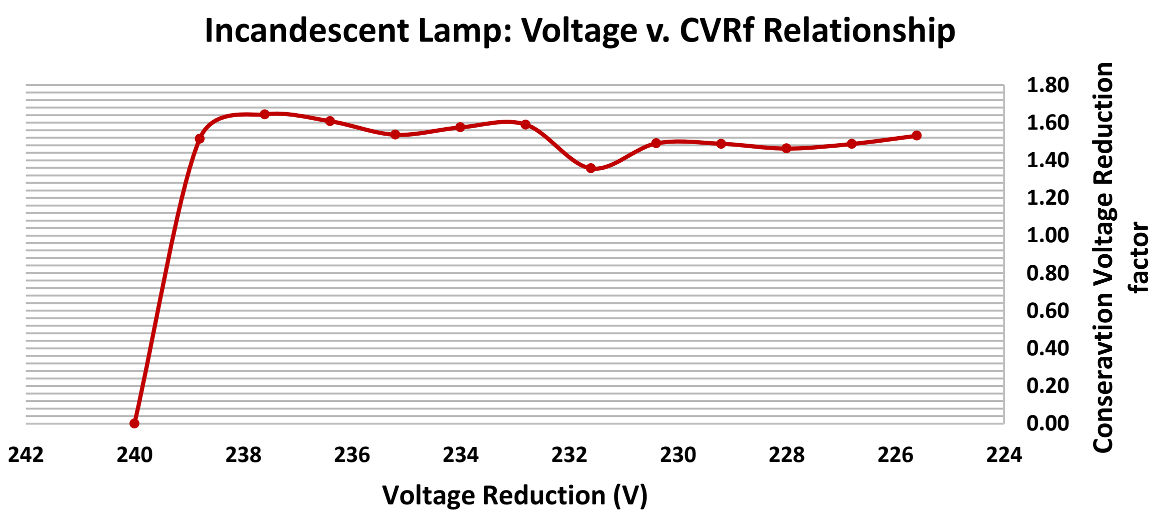

Figure 9 - Incandescent Lamp: Voltage v. CVRf Relationship

2.2 Fluorescent

The common and more efficient compact fluorescent lamp, combined with the LED (light emitting diode) lamp has allowed the phasing out the phasing out of incandescent lamps. The fluorescent lamp produces light from the collision of atoms within the gas filled tube.

2.2.1 Compromise

Exactly as the incandescent lamp demonstrates, the compromise with lighting devices is the light intensity output. As the voltage is reduced to the fluorescent lamp, the light output shall be monitored and documented, as per the incandescent lamp.

2.2.2 Testing Procedure

Testing the fluorescent lamp once again mimics that of the incandescent lamp. The fluorescent lamp shall be connected through the power meter and variable transformer. Once connected, the tube is placed within a small enclosure to remove all ambient light, with the light meter 1m for the lamp itself. With the voltage set at the required testing voltages, the current, energy, voltage and instantaneous power are measured. Again the lamp is left operating for 10 minutes to allow the appliance to adequately heat. At the 9 minute mark the light intensity (LUX) is measured and documented.

2.2.3 Voltage v. Energy

Figure 10 below does not present a flat line attributed with constant power devices. The energy consumption tends to fluctuate (discussed within 'Lighting Appliances Discussed'), when operated at the initial 240V the device consumes 3.5Wh. As the voltage is decreased a lowest energy consumption of 3.48Wh was recorded at 232.8V. At the minimum 225.6V the energy consumption resides at 3.49Wh, 0.29% lower than when operated at 240V.

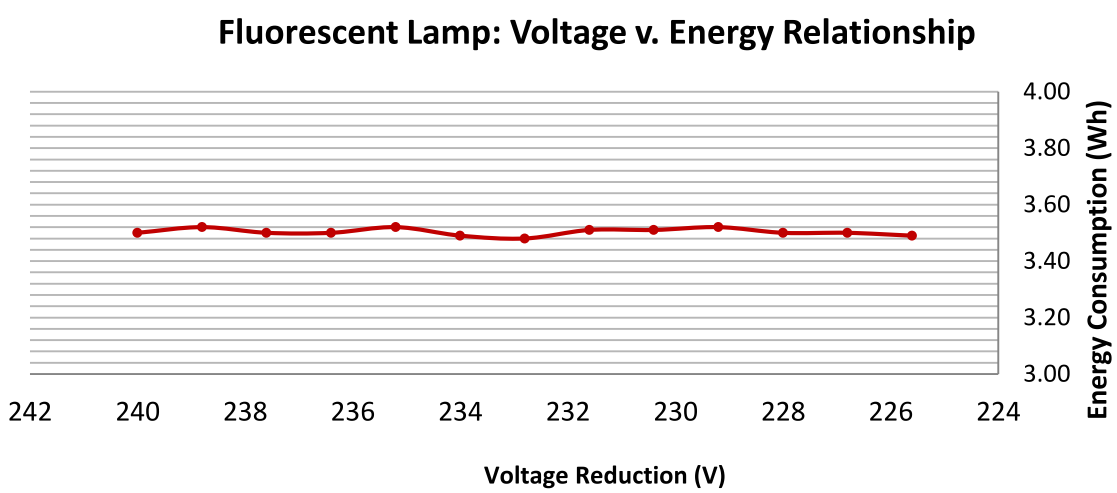

Figure 10 - Fluorescent Lamp: Voltage v. Energy Relationship

2.2.4 Voltage v. Power

The change in Instantaneous power with respect to voltage reduction can be observed in Figure 11. At the standard 240V supply voltage the fluorescent lamp consumes 21.18W. A slight downwards trend is attributed to the reduction in voltage, however slight increases can be observed, Falling to 20.35W at 235.2V, before increasing to 20.85W at 232.5V. The lowest power consumption could be recorded at 19.88W with the lamp operating at 226.8V. At the minimum 6.0% reduction or 225.6V the fluorescent lamp consumed 20.24W during the operating time, 4.44% lower than measured at 240V.

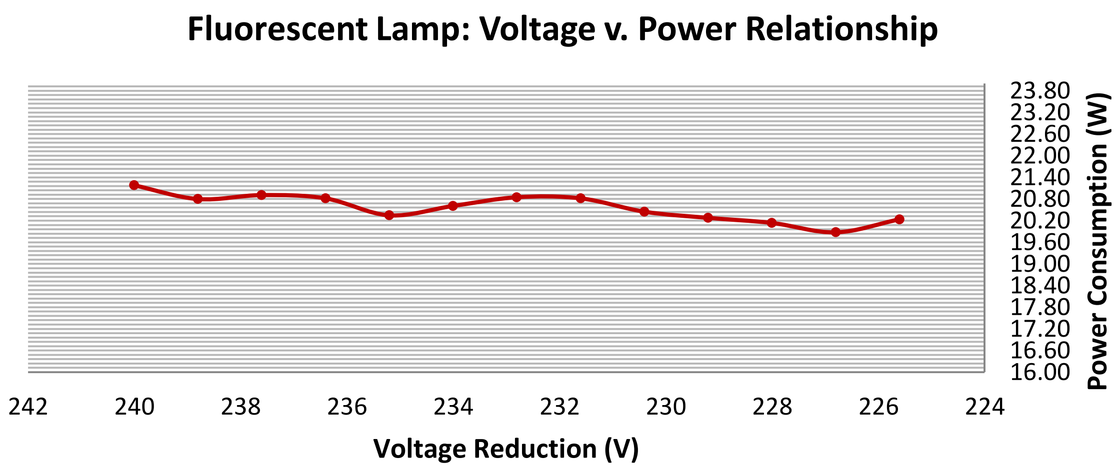

Figure 11 - Fluorescent Lamp: Voltage v. Power Relationship

2.2.5 Voltage v. Light Output (LUX)

Figure 12 shows the light intensity with respect to reduction in voltage, the first six 0.5% decrements in voltage showed 13.4% increase in LUX, increasing from 709LUX to 804LUX. From 234V the light provided intriguing results, dipping to 775LUX at 232.8V the light gradually increased once again to 794LUX at which point the light intensity tapers down to 772LUX. Beyond 234V, the fluorescent lamp light output gradually declines before finishing at 772LUX with a 6% voltage reduction.

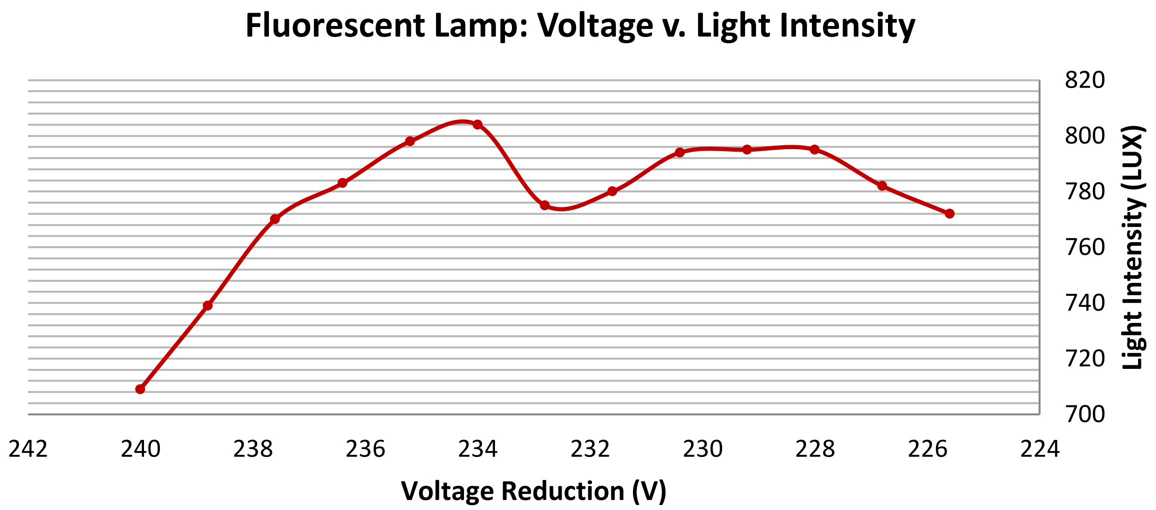

Figure 12 - Fluorescent Lamp: Voltage v. Light Intensity

2.2.6 Reduction Factor

The fluorescent lamp does not present a consistent reduction in energy under reduced voltage conditions. Decreasing the voltage 0.5% results in a $CVRf = -1.14$. As the voltage steadily declines the reduction factor does increase to $CVRf = 0.16$ at 232.8V. However overall fluctuates around the zero point. The average reduction factor produced by the fluorescent lamp being $CVRf = -0.11$.

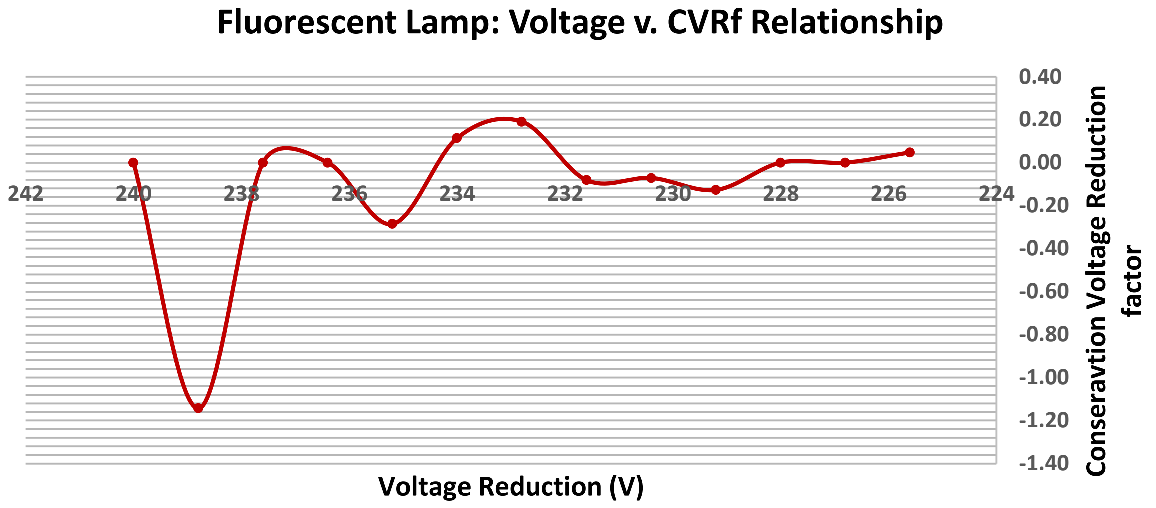

Figure 13 - Fluorescent Lamp: Voltage v. CVRf Relationship

2.3 LED (Light Emitting Diode)

As the demand for efficiency increases, lighting appliances has taken leaps in development. The Light emitting diode or simply LED type is by far the most efficient lighting type implemented in the modern home.

2.3.1 Compromise

As with both the incandescent lamp and the fluorescent lamp, the compromise to be measured against the reduction in voltage is light intensity.

2.3.2 Testing Procedure

As all the lighting devices operate in the same manner and serve the same purpose, that is to emit light, the light emitting diode shall be tested in the same manner as the other lighting devices. That is, the LED lamp was connected to the power meter through the variable transformer, as illustrated in Figure 5 and placed within the small enclose to prevent external lighting disturbance. The voltage was decreased in small decrements with power, energy, current, voltage and LUX recorded with each step. Each voltage decrement shall be operated for 10 minutes, with the light value recorded at 9 minutes.

2.3.3 Voltage v. Current

The LED is listed in the constant current loading type as seen in Figure 14. At 240V the light emitting diode draws 42.6mA. As the voltage is reduced, the light continues to consume essentially the same about of current, however in some cases the current draw slightly increased or decreased by 1.0mA. At the minimum regulatory limit the LED draws 42.18mA.

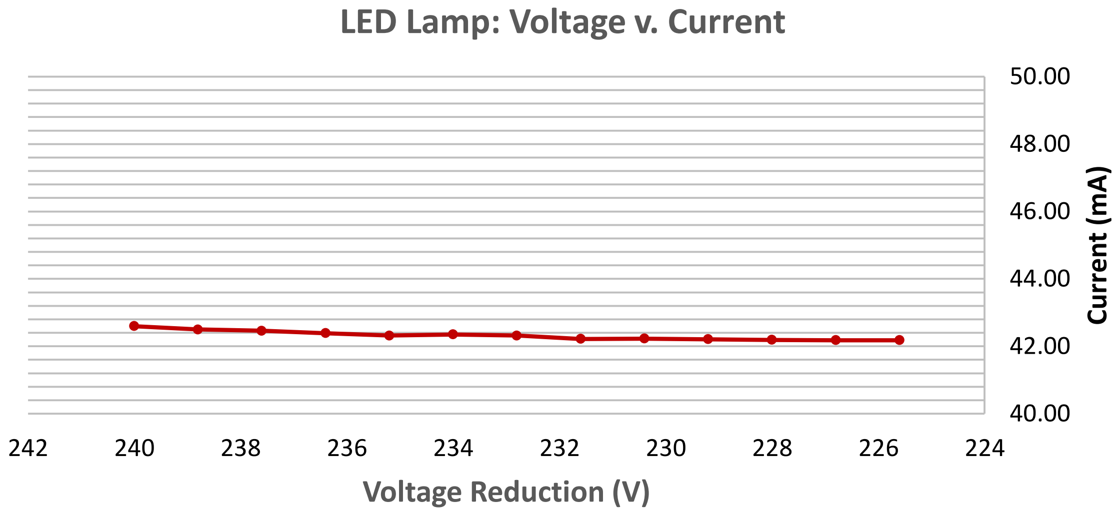

Figure 14 - LED Lamp: Voltage v. Current

2.3.4 Voltage v. Energy

As the LED is a constant current device, a reduction in energy consumption can be obtained through the implementation of voltage reduction. Figure 15 shows the reduction in energy consumption attributed to the reduction in voltage. At 240V, the LED consumed 1.6Wh when operated for 10 minutes continuously. Reducing the voltage to 232.8V / 3% reduction, sees the energy consumption decrease by 2.85% to 1.55Wh. With the maximum regulatory low voltage implemented the LED consumes 1.52Wh, 5.5% lower than the energy consumed at 240V.

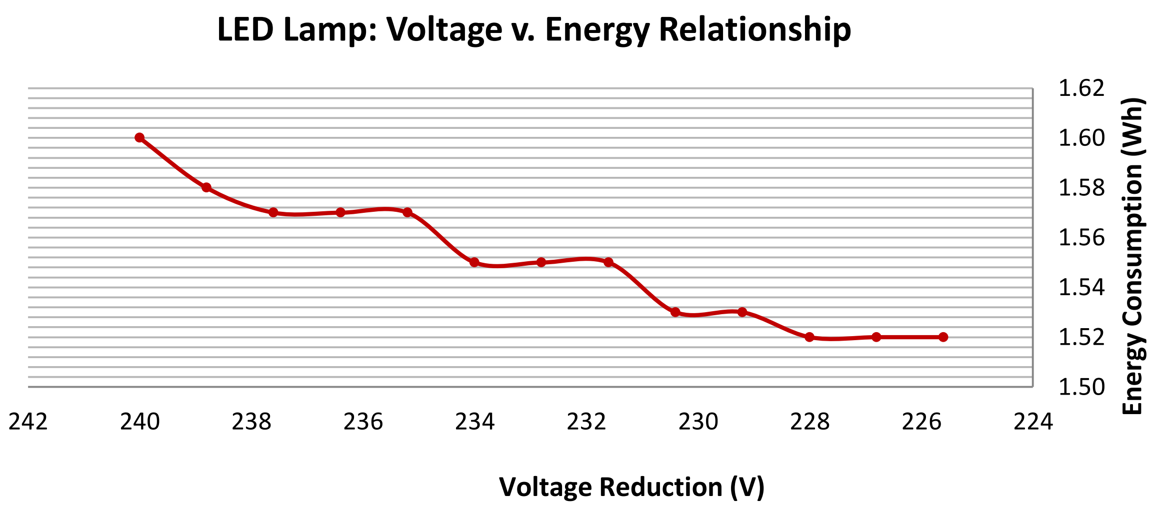

Figure 15 - LED Lamp: Voltage v. Energy Relationship

2.3.5 Voltage v. Power

Observing the power output for the LED, it becomes clear why the lighting type is implemented largely in modern construction. The power consumption is almost 1/10th that consumed by the incandescent lamp when operated at 240V. Since the device is constant current, as the voltage is reduced the power output decreases respectively. From consuming a tiny 9.46W whilst operating at 240V the power consumption steadily declines to 8.94W at 225.6, 5.5% less than the initial 240V.

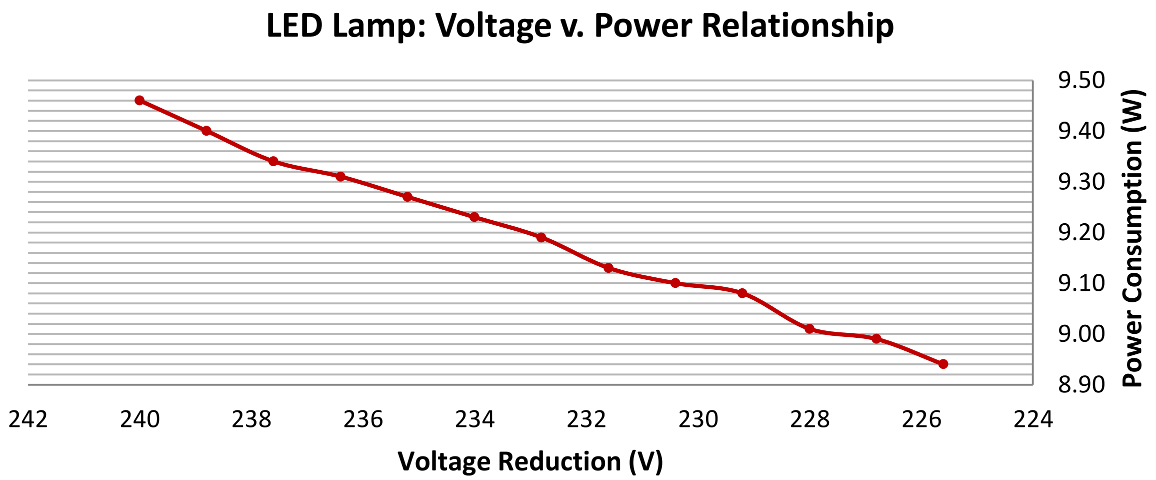

Figure 16 - LED Lamp: Voltage v. Power Relationship

2.3.6 Voltage v. Light Output (LUX)

Observing the light intensity compromise for the light emitting diode, Figure 17 shows the typical trend for reduced voltage operation. At 240V the LED output 213LUX, as the voltage decreased in 0.5% intervals the light output gradually decreases. Whilst operating at 232.8V (3% reduction) the common LED downlight produced 204LUX, decreasing 4.23% from the initial operation. Further reducing the voltage to the minimal 6% reduction in accordance with regulatory limits, the LED light produced a 199LUX, decreasing from the original operation voltage by 6.57%.

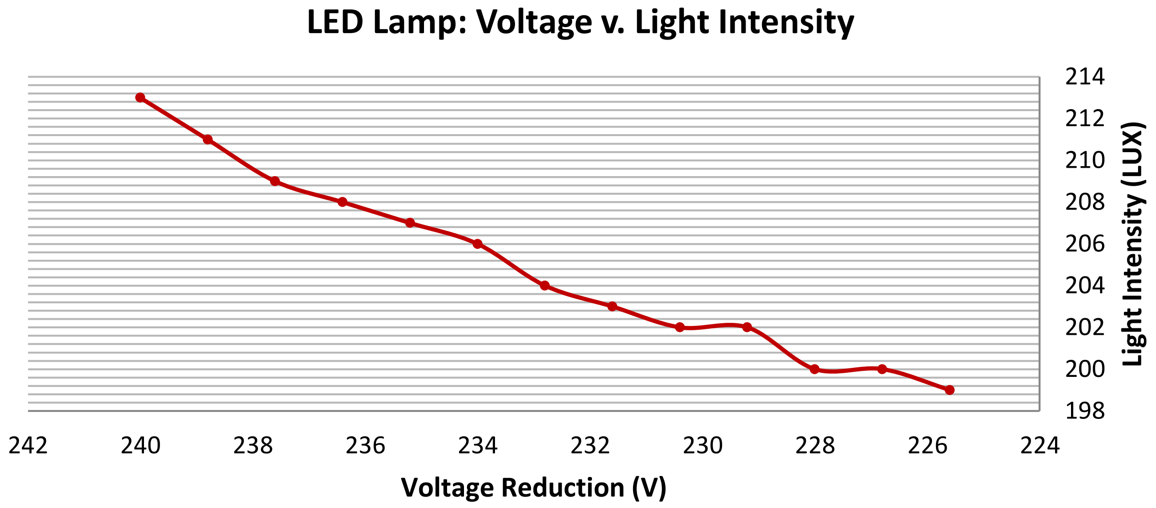

Figure 17 - LED Lamp: Voltage v. Light Intensity

2.3.7 Reduction Factor

The reduction in energy consumption / power draw of the light emitting diode under reduced voltage conditions can be qualified using the Conservation Voltage Reduction factor. The CVRf for each sample voltage can be seen plotted in Figure 18 below. When reduced by 0.5% the LED lamp produced a $CVRf = 1.27$, further reducing the voltage until the minimum 6% provided results ranging from $CVRf = 0.85$ to $CVRf = 1.06$, with the average $CVRf = 1.01$.

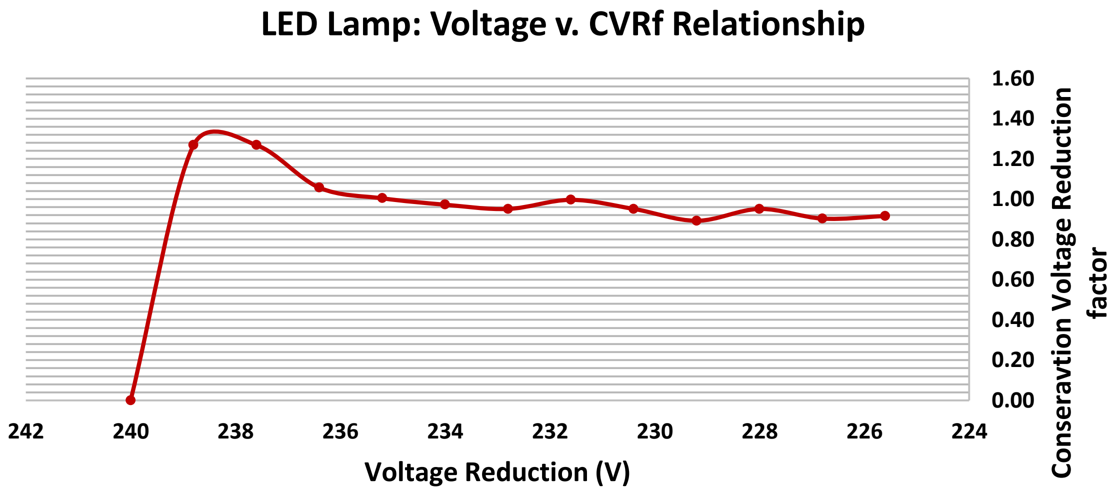

Figure 18 - LED Lamp: Voltage v. CVRf Relationship

2.4 Lighting Appliances Discussion

From the above results it can be concluded, CVR did provide a reduction in energy consumption, when implemented on the constant resistance incandescent lamp and the constant current light emitting diode. However, CVR did not provide viable results for the constant power fluorescent tube. It is important to note that there were variations in the magnitude of the AC voltage waveform at the GPO outlet (Further discussed under 'Summary and Future Works').

As far as acceptable lighting levels, the reduction of light and discomfort to an occupant are subject to room size, ceiling heights, floor and wall finishes etc. However, for a typical small home, bedroom, the light outputs presented from all three lights lamps would provide sufficient lighting to perform general task. Screen based work, such as typing, computer Aided Design etc. where occupants are focused on a computer screen for extended periods of time, will require a higher LUX and may experience some discomfort with the three lamps operating at a reduced voltage.

2.4.1 Incandescent Lamp Discussion

The incandescent lamp, although essentially phased out, showed the greatest reduction in energy consumption and power draw under all decrements in voltage, as expected for this load type [3]. This constant resistive device produced a low CVRf of 1.36 and a high of 1.64, not drastically far from the ideal $CVRf = 2.0$, as discussed under the load types and 'Conservation Voltage Reduction (CVR) Technique: An Application Guideline for a SAmart[er] Grid' [11]. Of the three tested lighting devices, the incandescent lamp had the greatest reduction in light output, depleting 22.31% from original operating conditions.

Observing Figure 6 and Figure 7, the results presented do not correspond to the results expected based on equation 2. It is speculated that the device, since containing a tungsten element, is subject to a change in resistance as the element varies in temperature and as a result closely resembles a linear relationship result rather than the expected quadratic relationship. Based on the above graphs and the complete data spread in Appendix A - Incandescent Lamp, given the light output decreases marginally under the slightly higher voltages but still provides quantifiable energy savings, a reduction from 0.5-2.0% seems ideal.

2.4.2 Fluorescent Lamp Discussion

The fluorescent light, unlike the incandescent lamp, falls into the constant power category. Prior to testing it could be assumed the lamp would remain completely unaffected due to the load category the device is contained within. From the results it can be concluded that at best, the fluorescent lamp presents a minute reduction in energy consumption. The CVR plot shows minor fluctuations about the zero point, peaking at 0.19. These fluctuations could be attributed to potential losses within the fluorescent lamp driver or error in the measurement. Unless the house contained an excessive quantity of fluorescent light fittings little no savings in energy consumption would be achieved.

Interestingly, the compact florescent lamp moderately increased in light output from 709LUX recorded at 240V to 801LUX at 232V, before saturating. Since an increased light output could be noted from reduced voltages, numbers of light fittings installed could be potentially be reduced and result in energy consumption savings in this respect.

2.4.3 LED Discussion

Finally the most efficient lighting type tested was the light emitting diode (LED). From research paper [3] it was noted that the LED is a constant power type load. As a result, the power should remain constant, resulting in no reduction in energy consumption, hence a $CVRf = 0.0$. Figure 14 show this particular LED as a constant current device. The LED provided and average $CVRf = 1.01$, while fluctuating about the 1.0. These energy savings may be attributed to the lighting ballast and not the light itself, however it is important to note that every LED type lamps comes with an electronic driver and should these results be seen across each lamp type, the energy reduction could be quantifiable. Considering the efficiency and LUX varied only 6.57% during minimum reduced voltage conditions, CVR would indeed reduce energy consumption whilst deviation in light output would be observed.

CHAPTER 3. Heating and Cooling Appliances

Heating and cooling appliances are exactly as the name suggests, devices which provided heating and cooling to personnel, consumable items etc. Chapter 3 explores the operating efficiency during reduced voltage conditions of four appliances adopted in the majority of modern homes, an electric toaster, electric kettle, microwave and refrigerator. Connected as per the 'Connection Diagram', Figure 5, these devices were operated and tested under reduced voltage conditions, while power, energy, current, voltage and each devices compromise was measured. From the measured data and implementing equation 1, the device CVRf can be calculated.

So long as they are operated within the manufacturer's specification, these devices can be operated at reduced voltages, as low as the regulatory limit. No Australian Standards govern the voltage or operation for any of the four devices discussed under this chapter. When considering the compromise for heating and cooling devices contained within residential homes, once again it is simply the occupant's decision to select their desired operation should CVR be implemented. Provided the compromise doesn't deviate severely from the original operating conditions, as a result of reduced voltages and provided no discomfort is brought and occupants are satisfied with the operation, the reduction in voltage shall be considered acceptable.

3.1 Electric Toaster

Developed in 1893 [16], the electric toaster has grown to become one of the most widely adopted appliances. Operating as a typical constant resistive device, the toaster is fitted with wire varying in gauge and length, depending on the build and manufacturer. Large currents are driven through this resistive wire generating radiant heat (The wire will typically glow red hot) and with slices of bread placed beside the heating elements, the radiant browns the bread. Typical operation sees the bread contained within the toaster being heated for a user selected variable time. When the cooking time is ended the toast will emerge from the toaster and the heating elements switch off.

3.1.1 Compromise

With each appliance there is a very important compromise, which must be considered when reducing the voltage in an attempt to minimize energy consumption. The electric toaster, as mentioned above, contains heating elements (with a fixed resistance) inside the appliance, as the input voltage is reduced, instantaneous power decreases as per equation 2, resulting in a reduced radiant heat output, potentially to a point of not operating, as the manufacturer designed. Voltage reduction should only be implemented as far as the toaster continues to provide the manufacturers intended operation.

3.1.2 Testing Procedure

Measuring the energy consumption at a reduced voltage initially seems a very straight forward task. Reduce the voltage and operate the appliance. However, the above mentioned compromise requires consideration. Testing the device requires a procedure which not only captures the energy consumption but also the compromise.

For the electric toaster, as mentioned above, the additional quantity being monitored is the heating element temperature. The device shall be operated for precisely 60 seconds at each voltage decrement in which time the voltage, power, current, energy consumption and temperature shall be measured. The temperature produced by the toaster shall be measured using an infrared laser LCD thermometer, aimed directly at the heating element from a fixed 50cm distance.

3.1.3 Voltage v. Energy

The reduction in the electric toasters energy consumption as a result of voltage reduction can be seen in Figure 19 below. Initially operating at 240V the toaster consumed 15.12Wh during the 60 seconds of operation. With the voltage reduced by 3% the toasted measured a consumption of 14.03Wh, 7.20% lower than the original state. The greatest reduction in energy consumption was obtained when the entire 6% voltage reduction was applied, consuming 13.00Wh, presenting a 14.01% reduction in energy consumption compared to the initial 240V.

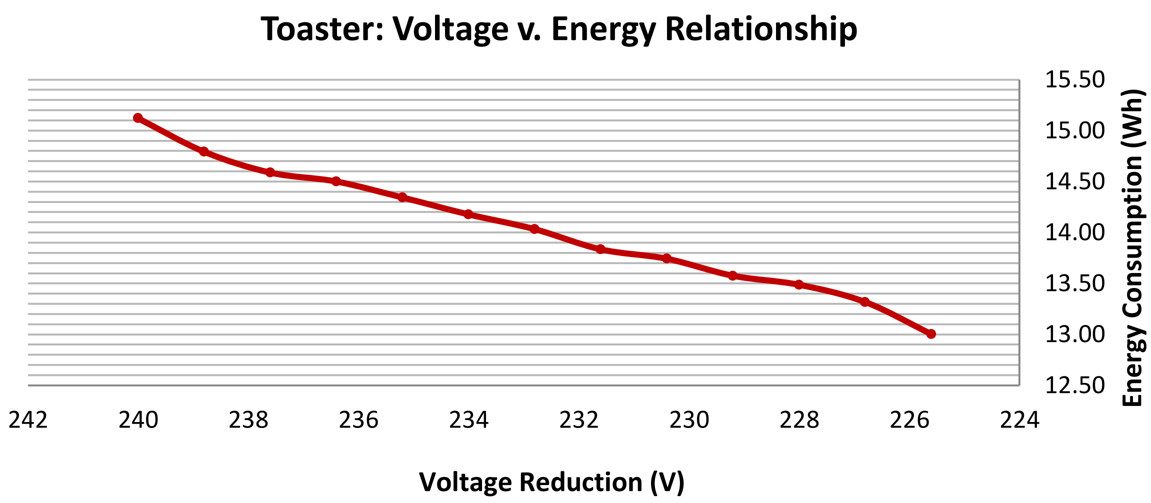

Figure 19 - Toaster: Voltage v. Energy Relationship

3.1.4 Voltage v. Power

Figure 20 below shows an almost identical plot to the 'Voltage v. Energy Relationship' seen above, which is expected as the energy consumption is a result of instantaneous power consumption over time. Comparing the 0%, 3% and 6% voltage reduction states, power values of 907.23W, 841.93W and 780.13W can be measured respectively. These reductions in power values present a change of 0%, 7.20% and 14.01% respectively.

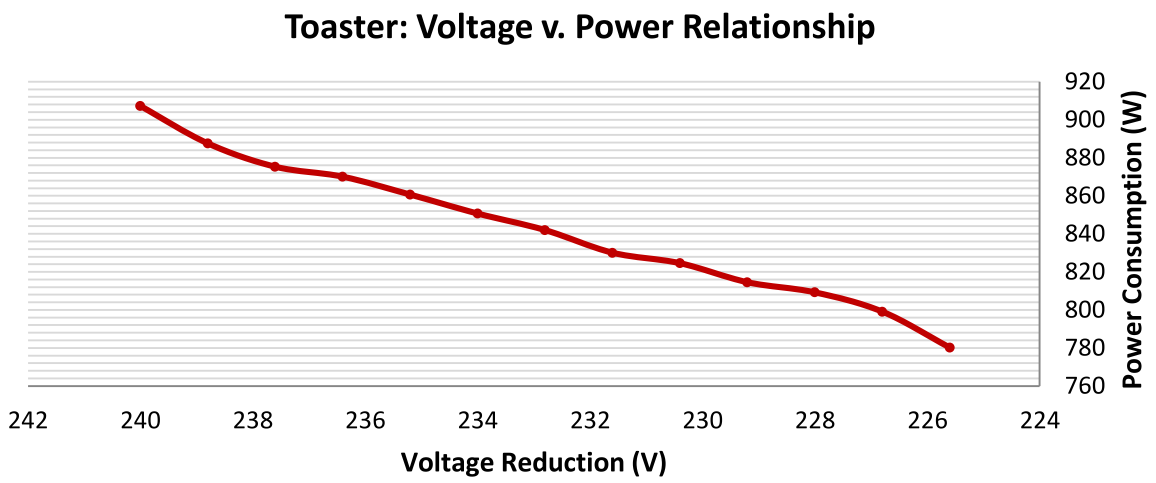

Figure 20 - Toaster: Voltage v. Power Relationship

3.1.5 Voltage v. Temperature

Considering the important compromise associated with the toaster, the heat element temperature, as a result of voltage reduction, can be observed in Figure 21 below. Operating at 240V the electric toasted produced 488.90°C, reducing the voltage to the 3% mark the temperature decreased to 472.90°C, falling 3.27% from the initial value. Reducing the voltage to the lower regulatory limit the temperature reduced further to 454.00°C, 7.17% difference from the standard delivery voltage of 240V.

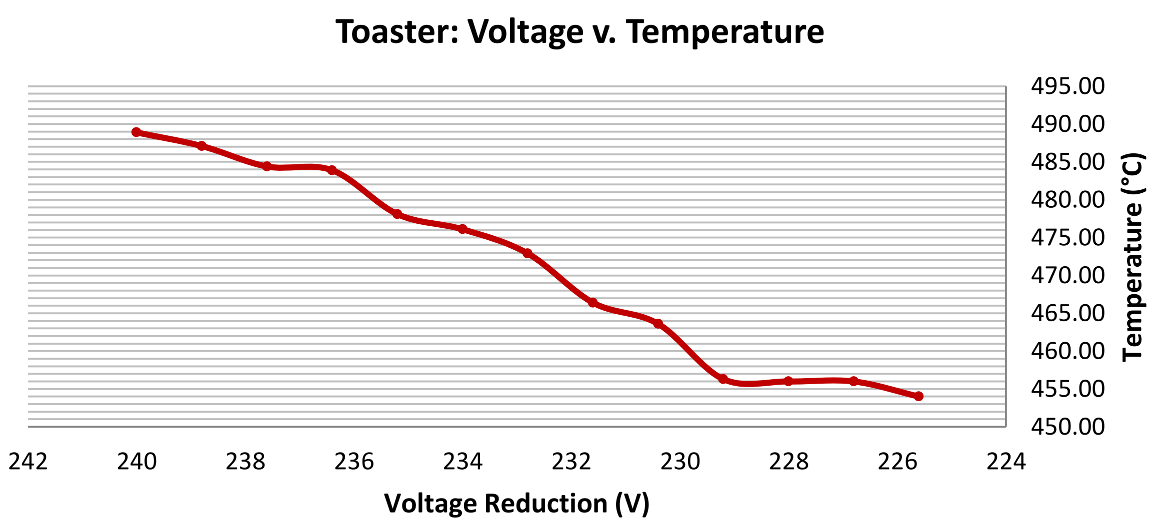

Figure 21 - Toaster: Voltage v. Temperature

3.1.6 Reduction Factor

For each increment in voltage reduction, the associated reduction in energy consumption (%ΔE) has been calculated (Refer Appendix D). Viewing the results below, Figure 22 shows the corresponding CVRf's as a result in voltage reduction. Between 0.5%-2.0% voltage reduction, the reduced energy consumption equates to a $CVRf = 3.53$ at 238.8V and $CVRf = 3.52$ at 237.6V (-0.5%) below 237.6V the efficiency fluctuates slightly between $CVRf = 2.74$ at 236.4V and $CVRf = 2.16$ recorded at 228V.

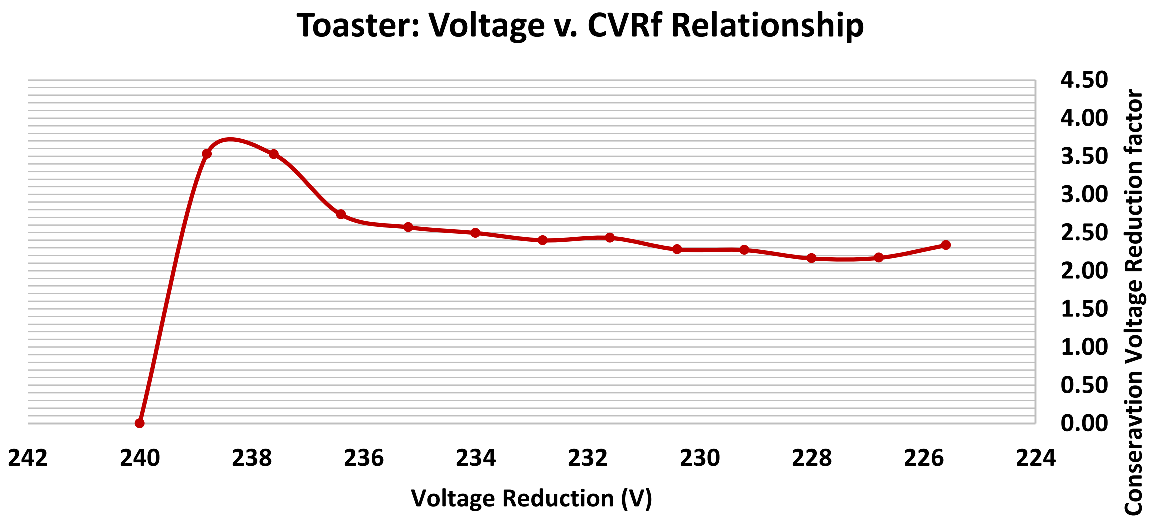

Figure 22 - Toaster: Voltage v. CVRf Relationship

3.2 Kettle No.1

The electric kettle, much like most of the devices listed in this report, is utilized extensively in the modern home. Used to boil water, this appliance is operated during all hours of the day. The device operates by driving large currents through a resistive core, where the core is contained inside the kettle, submerged in water and is positioned such that when switched on, heat can transfer from the core to the water.

3.2.1 Compromise

The kettle is a constant resistance device containing heating elements. However, temperature shall not be the compromise in this case, rather the time taken to heat the water to a particular temperature. A reduced power output, due to the voltage reduction, increases the time taken to heat the water. This shall allow energy to be appropriately quantified as well as the compromise.

3.2.2 Testing Procedure

To provide consistent, accurate measurements the kettle was filled with precisely 1000mL of fresh water and allowed to heat up to 60°C. Connected through the power meter and variac as per Figure 5, the 1000mL of water in the kettle was repeatedly heated up for each 13 voltage conditions, to 60°C. Each run, the time required to heat the water to the above mentioned temperature was recorded along with the voltage, current, power and energy consumption. The water was replaced with fresh ambient temperature water between each test to provide consistent results.

3.2.3 Voltage v. Energy

Figure 23 below presents the voltage vs. energy relationship for the electric kettle. At the starting 240V input, the device consumed 101.26Wh in order to heat the 1000mL of water to 60°C. Reducing the voltage to 232.8V (3% reduction) the device now consumed 100.5Wh to achieve the same task. Finally at the regulatory low 225.6V the appliance consumes 96.84Wh, 4.36% less than recorded consumption, while operating at 240V.

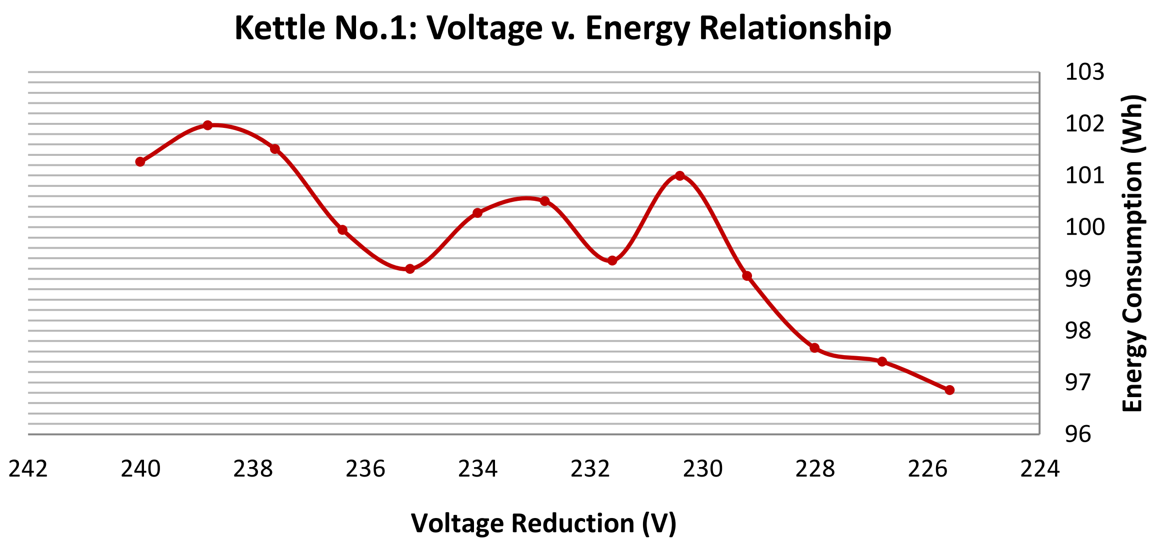

Figure 23 – Kettle No.1: Voltage v. Energy Relationship

3.2.4 Voltage v. Power

The above trend of reduced energy consumption is attributed to the data shown in Figure 24. Comparing once again, initial, central and final state results. At 240V supply voltage, the kettle consumes 2001.28W. Reducing the voltage presents a steady decline, at 3% reduction the electric kettle now consumed 1886.15W, 5.75% less instantaneous power. Reducing the voltage to 225.6V the kettles power consumption further reduced to 1770.52W, 11.53% lower than that recorded during the 240V testing.

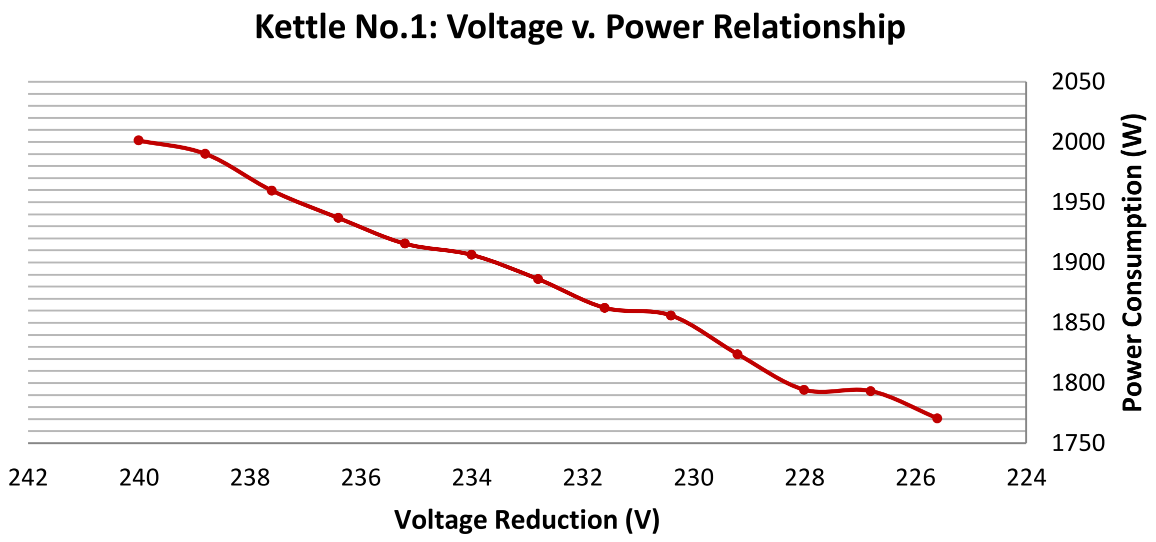

Figure 24 – Kettle No.1: Voltage v. Power Relationship

3.2.5 Voltage v. Time

Under normal operating conditions, 240V (0% reduction) the kettle operated for a total time of 3 minutes and 3.6 seconds to conduct heat to allow the water to reach the desired 60°C. Figure 25 shows as the voltage descends as low as 225.6V the time gradually increased to 3 minutes and 28.2 seconds, increasing 13.4% for a 6% decrease in voltage. At the 3% voltage reduction midpoint, the kettle required 3 minutes and 19.8 seconds to heat the water, 8.77% longer than at 240V.

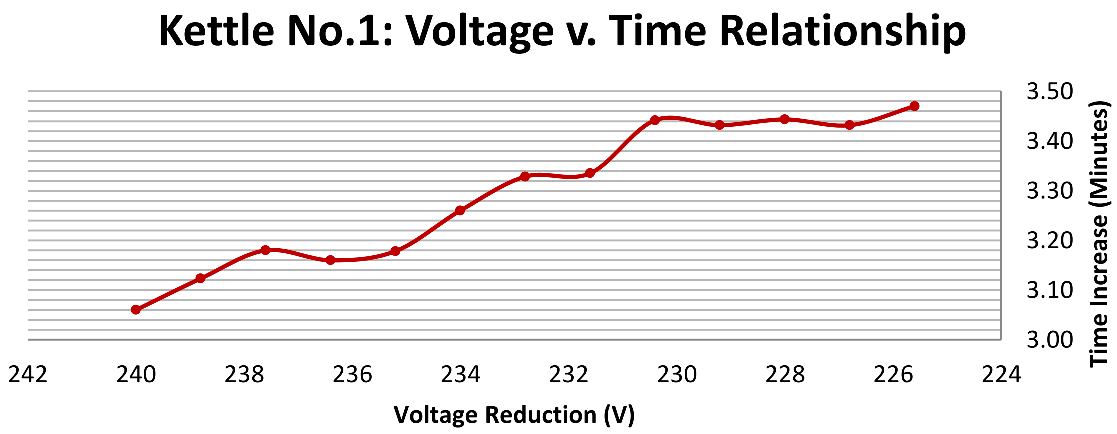

Figure 25 – Kettle No.1: Voltage v. Time Relationship

3.2.6 Reduction Factor

Importantly Figure 26 displays the $CVRf$ for each 0.5% decrement in mains voltage. At 238.8V, the device produced a reduction factor of $CVRf = -3.01$. With a 2% reduction in voltage (235.2V) the kettle operated for 0.12 additional minutes, resulting in the device's highest reduction factor of $CVRf = 0.29$. Further reducing the voltage resulted in a slight decline before residing at a reduction factor $CVRf = -0.05$ at the lowest regulatory 225.6V.

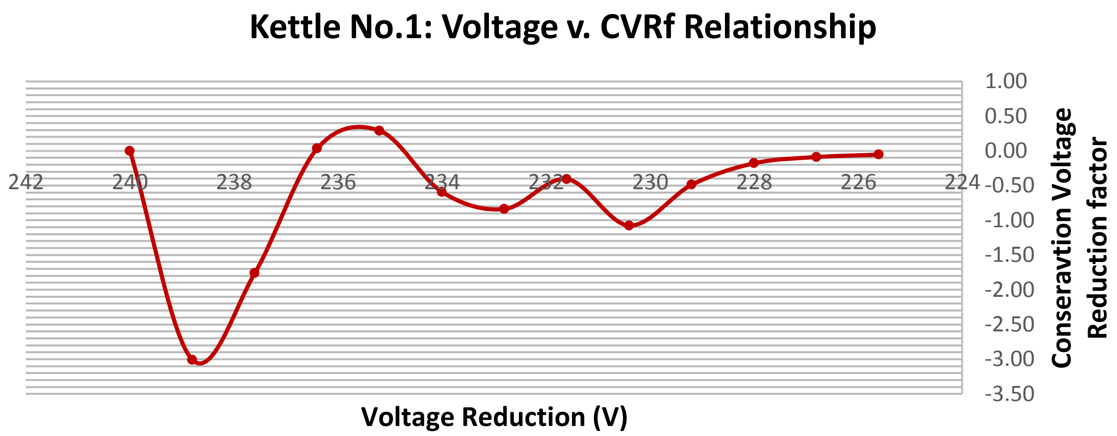

Figure 26 – Kettle No.1: Voltage v. CVRf Relationship

3.3 Kettle No.2

3.3.1 Compromise

Kettle No.1 seen the device be timed to heat a body of water to a 60°C set point, kettle No.2 shall again be tested whilst considering time as the compromise. However, this time the kettle shall be allowed to complete its cycle and turn off at 100°C (boiling point) via the thermostat control and not at a particular lower temperature.

3.3.2 Testing Procedure

Connected as per Figure 5, the kettle was filled with precisely 1000mL of water. Operation time was recorded from the start, until the devices is turned off by the thermostat control. During this time, the voltage, current, instantaneous power and energy shall be recorded. This procedure shall be undertaken for each decrement in voltage.

3.3.3 Voltage v. Energy

With the kettle operating and turning off via the self-controlled thermostat, the energy consumption results with respect to each voltage decrement can be seen in Figure 27. At 240V this kettle consumed 96.4Wh, however as the voltage decreased, the energy consumption increased. At 232.8V the kettle consumed 102.8Wh, 6.64% more energy than when initially operated. Further voltage reduction to 252.6V sees the energy consumption increase to 104.9Wh, 8.82% higher than at 240V. A peak high energy consumption of 109.6Wh was recorded at 228V.

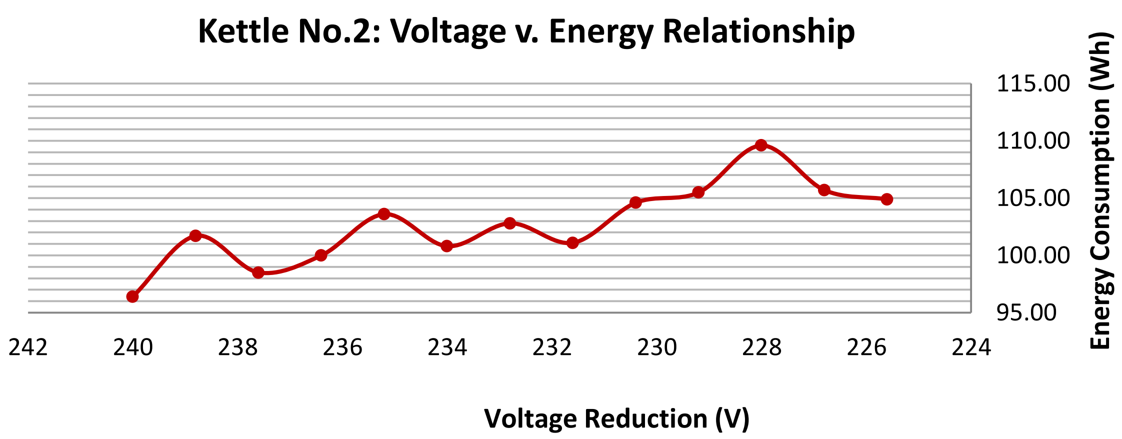

Figure 27 - Kettle No.2: Voltage v. Energy Relationship

3.3.4 Voltage v. Power

Instantaneous power draw proved to steadily decline, Figure 28. Initially consuming 2127.74W at 240V, as the voltage reduced to 232.8V the power reduced to 1998.38W, 6.08% lower. With the lowest regulatory voltage limit implemented, a power consumption of 1852.74W was measured, 12.92% lower than when operated at 240V.

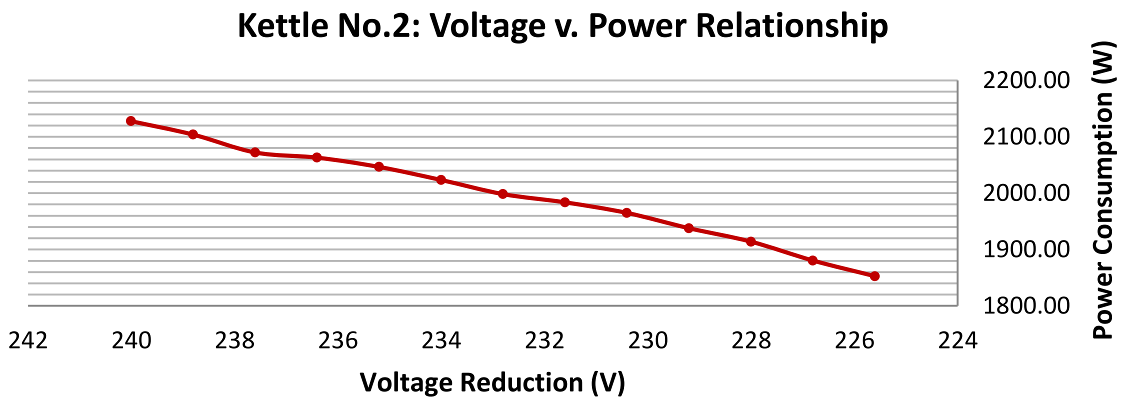

Figure 28 - Kettle No.2: Voltage v. Power Relationship

3.3.5 Voltage v. Time

Whilst operating at the standard delivery voltage, 240V this kettle required 2.72 minutes to boil and turn off via the thermostat, Figure 29. With the voltage reduced 3%, the time taken again boil the water required 3.10 minutes. Each decrement in voltage see's the time required to boil the water steadily increase. At 225.6V, the kettle required 3.41 minutes, 25.32% longer than the initial required time.

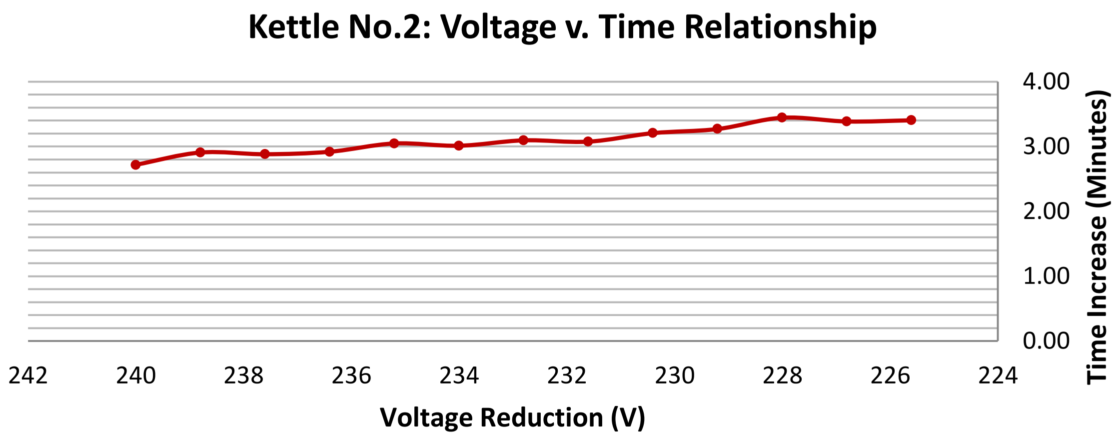

Figure 29 - Kettle No.2: Voltage v. Time Relationship

3.3.6 Reduction Factor

Whilst operating and shutting off via the thermostat control, the kettle provided no energy reduction with a reduction in voltage, see Figure 30. With 0.5% voltage reduction, the efficiency fell, producing a reduction factor $CVRf = -11.00$. At the next voltage decrement, 1%/237.6V, the energy consumption did decrease from that recorded at 0.5%, however it still provided a negative reduction factor of $CVRf = -2.18$. From 1% onwards, the reduction factor fluctuates below zero, producing only negative results with a reduction factor $CVRf = -1.47$ at 225.6V.

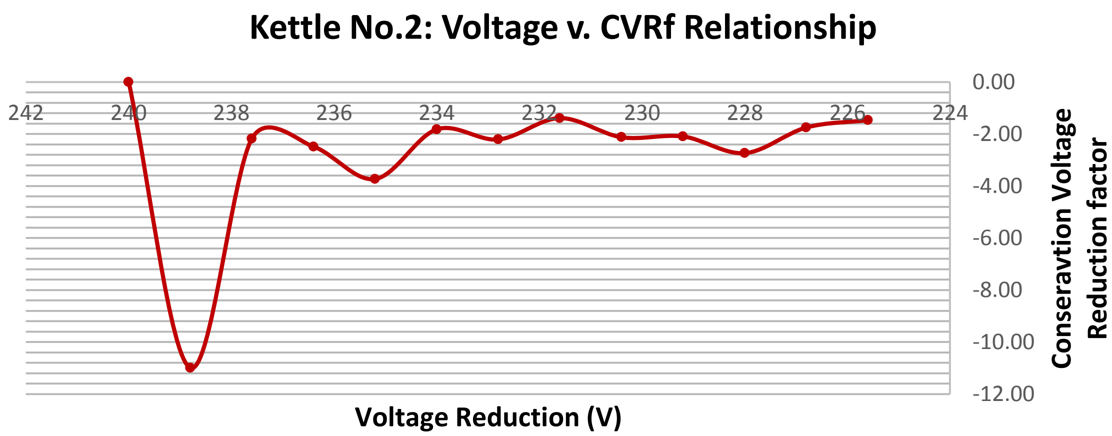

Figure 30 - Kettle No.2: Voltage v. CVRf Relationship

3.4 Microwave

The microwave oven, as the name suggests, is a heating device which utilizes microwave radiation to heat food items. Microwave radiation is in the microwave oven produced by vacuum tubes; that generate electromagnetic radiation with modern microwave ovens producing a frequency of 2450MHz [15]. Reviewing the results for this appliance within Appendix F – Microwave, it becomes clear the microwave oven falls into the constant current load type. Equation 3 mathematically explains the relationship of power and voltage, when the current remains constant. That is, as the voltage reduction is implemented, the resulting power is reduced.

3.4.1 Compromise

A common trend can be seen across the heating and cooling devices. The microwave, much like kettle and toaster, is heavily dependent on the heat produced. When voltage is reduced incrementally the temperature can be seen to reduce. With the temperature output decreasing as the voltage is reduced, the microwave's runtime may require increasing to heat a food item to the desired temperature. Therefore, a compromise must be established between the voltage reduction, energy savings and heat output.

3.4.2 Testing Procedure

It has been established heat the compromise for heating and cooling appliances is time and heat, instantaneous power output and time required to heat to a particular temperature. To accurately test the microwave, it was desired to keep as many variables as possible constant. Therefore, to provide consistent accurate results, connected as per Figure 5, 300mL of fresh water was contained within a plastic cup and heated within the microwave on the same 'High' settings for 3 minutes. At the 3 minute mark the water was removed from the microwave and temperature recorded. For each test the water was emptied and replaced with fresh water to provide equal initial temperature before each test. This test was undertaken for all 13 voltages.

3.4.3 Voltage v. Current

As the device is constant current, the voltage vs. current plot shall first be observed, Figure 31. Whilst operating at 240V the microwave drew 4.19A. With 3.0% voltage reduction implemented the device draws 4.20A, 0.01A difference from the initial recording. Finally at 225.6V the appliance drew 4.21A, 0.02A difference from 4.19A recorded during the 240V testing.

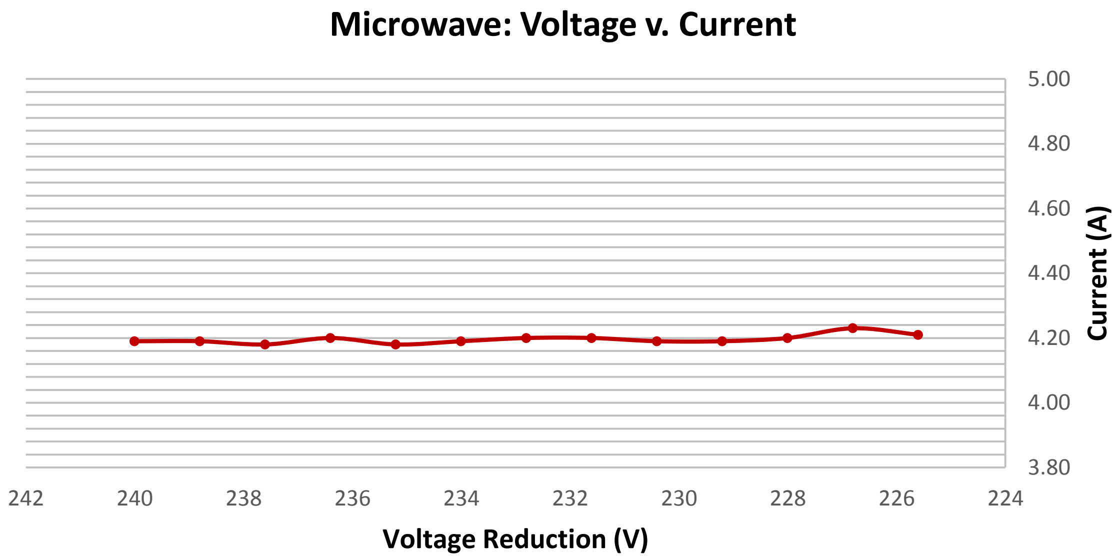

Figure 31 - Microwave: Voltage v. Current

3.4.4 Voltage v. Energy

The voltage v. energy relationship can be seen in Figure 32. As measured by the power meter, the microwave had decreasing energy consumption, as a result of voltage reduction. At 240V the microwave consumes 46.6Wh when operated for 180 seconds. With the same operating time frame, at 3% reduction (232.8V) the microwave recorded a consumption of 45.0Wh and 43.6Wh when operated at the lowest 225.6V. From initial to final state, 6% voltage reduction, a reduction in energy consumption of 5.95% could be seen.

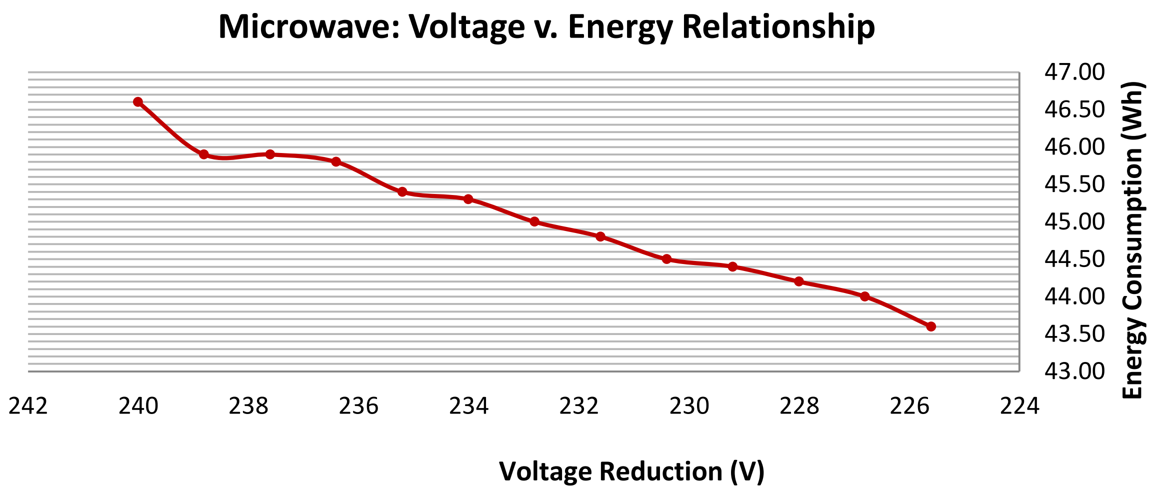

Figure 32 - Microwave: Voltage v. Energy Relationship

3.4.5 Voltage v. Power

The reduction in energy consumption is directly related to the reduced power consumption. The microwave showed a decrease in power consumption as the voltage reduced, resulting from a constant current type loading. At 0% reduction or 240V the microwave consumed 937.5W instantaneous power, while under 3% and 6% voltage reduction, the power draw was 911.4W and 881.7W respectively. From the initial to the regulatory low voltage, the power consumption recorded a reduction of 5.95% for a 6% reduction in voltage.

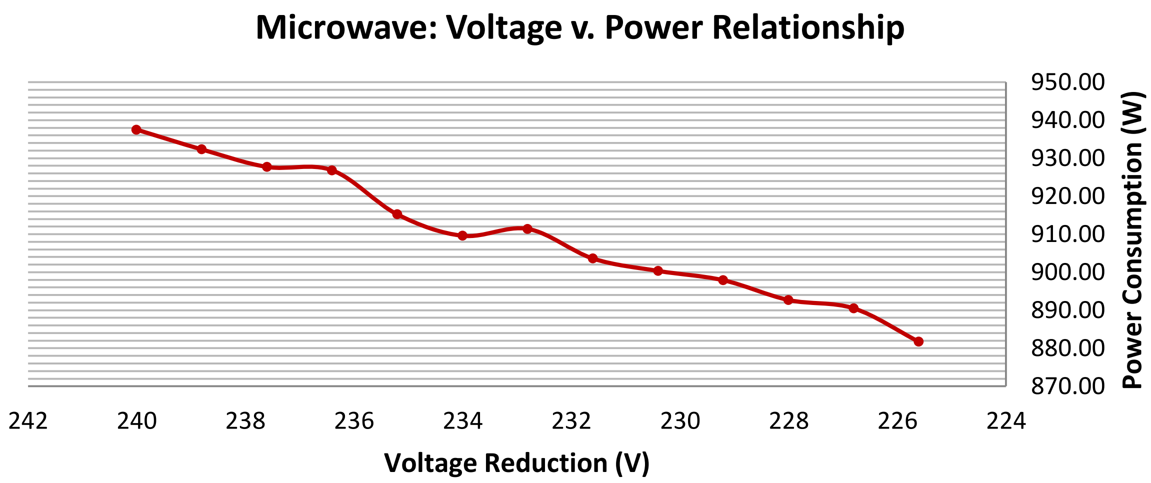

Figure 33 - Microwave: Voltage v. Power Relationship

3.4.6 Voltage v. Temperature

Figure 34 below plots this reduction in heat with respect to decreasing voltage adjustments. Small high points can be observed at the 1% and 1.5% reduction voltages, these present a heat increase of 1.33% and 0.8%. As the voltage was further reduced, the water temperature showed to decrease as much as 8.8%, from the 37.5°C produced at 240V to 34.2°C produced at 225.6V.

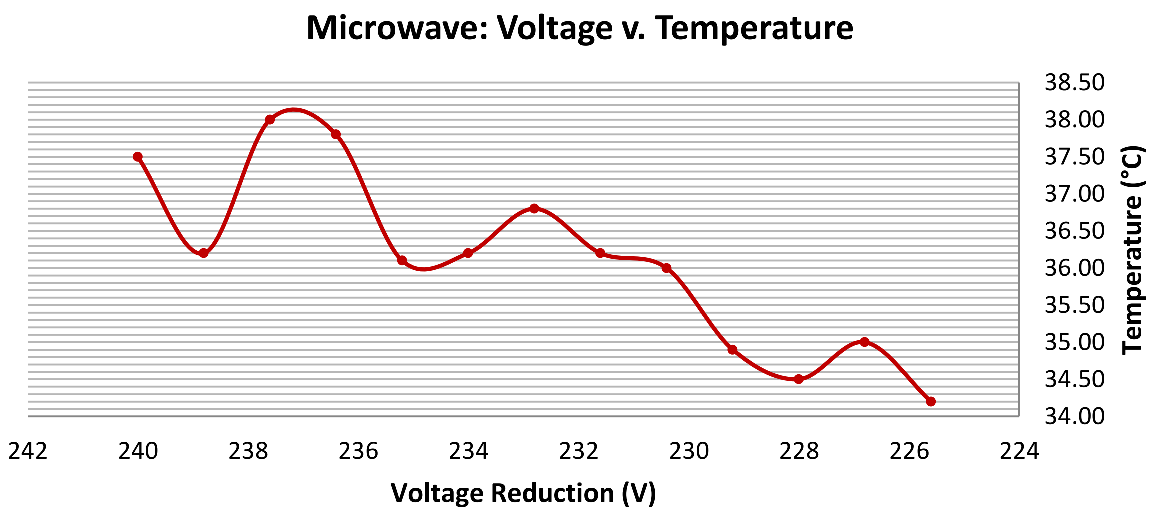

Figure 34 - Microwave: Voltage v. Temperature

3.4.7 Reduction Factor

Implementing Equation 1 for the measured data, the Conservation Voltage Reduction factor has been calculated for each incremental decrease in voltage to the microwave. Observing Figure 35, CVR factors for the device ranged from the smallest, reduction factor of $CVRf = 0.76$ at 236.4V to highest reduction factor $CVRf = 1.19$. With the voltage adjusted to the lowest regulatory limit the microwave produced a reduction factor $CVRf = 0.99$.

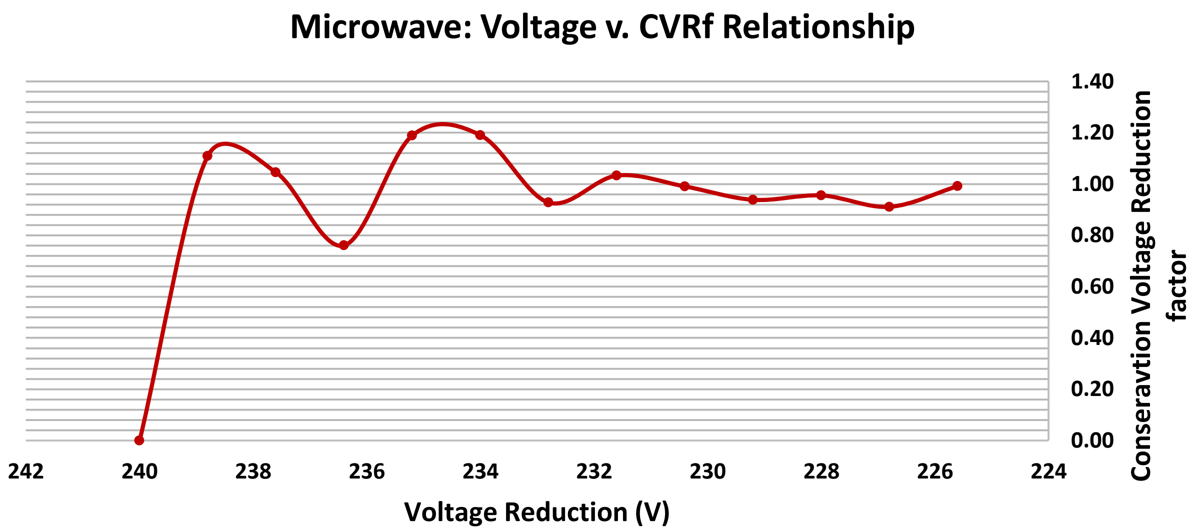

Figure 35 - Microwave: Voltage v. CVRf Relationship

3.5 Refrigerator

3.5.1 Compromise

The purpose of this device is to provide a cold liquid to pass through the refrigerator, absorbing the heat from within. As the voltage supply is reduced the temperature within shall be monitored using a wireless thermometer. Should the device become far too warm to operate affectively, despite potentially consuming less energy, voltage reduction shall be deemed impractical for this device.

3.5.2 Testing Procedure

As per previous devices, the refrigerator shall be connected, as per the 'Connection Diagram' Figure 5. Operating consistently, the power, energy, current, voltage and temperature shall be documented every 12 hours. The refrigerator is to be used under normal conditions, opening the door as necessary. The wireless thermometer transmitter shall be fixed in a single location within the fridge to provide consistent temperature results.

3.5.3 Voltage v. Energy

Figure 36 below presents the reduction in energy consumption with respect to a reduction in voltage. Whilst operating at the standard 240V, with no voltage reduction applied, the refrigerator consumes 1172.7Wh during a 12-hour time period. Reducing the voltage in 0.5% decrements to energy consumption lightly fluctuates. At 232.8V or 3.0% voltage reduction 1065.1Wh is consumed, 9.18% less than under initial operating temperature. With the lower regulatory voltage set, 225.6V / 6.0%, the refrigerator consumes 1111.5Wh, 5.22% lower than the 240V energy consumption.

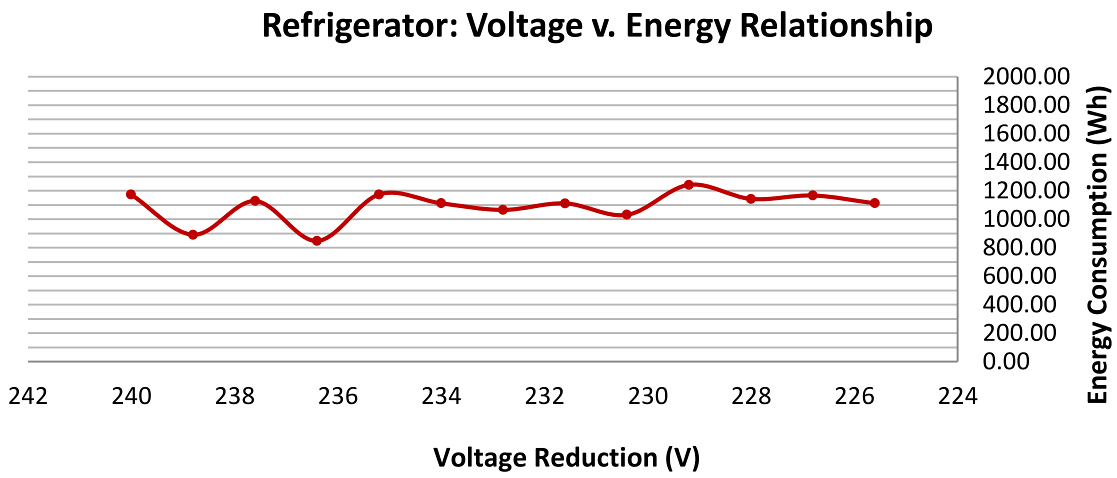

Figure 36 - Refrigerator: Voltage v. Energy Relationship

3.5.4 Voltage v. Power

The above energy consumption curve is directly related to the instantaneous power draw over time. Figure 37 plots the instantaneous power for each decrement in supply voltage. It is important to note, these instantaneous power values are recorded as the fridge is operating. At 240V whilst cycling the fridge consumes 200.1W, as the voltage is progressively reduced, much like the energy consumption the power fluctuates around this value. A peak of 226.97W had be recorded at 231.6V at 226.9V, while hovering around the 179W region for the majority of tested voltages.

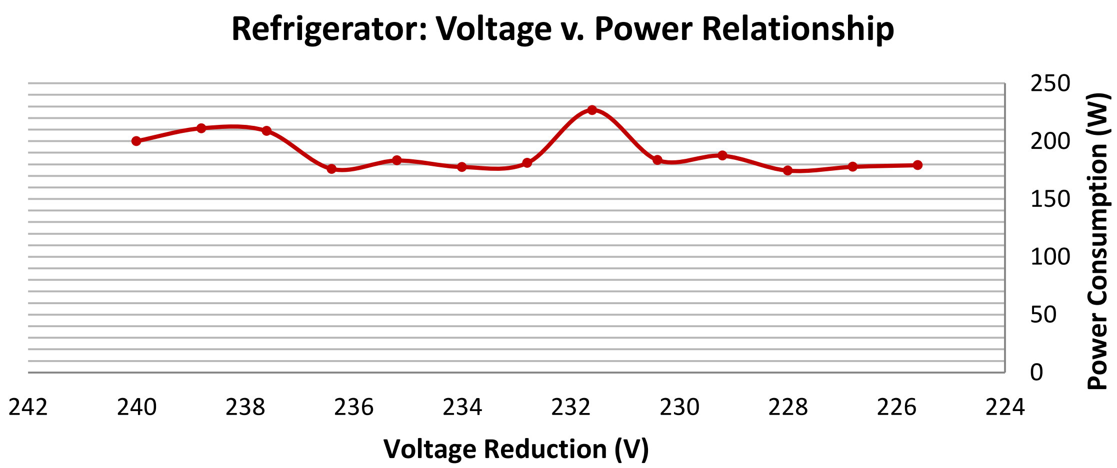

Figure 37 - Refrigerator: Voltage v. Power Relationship

3.5.5 Voltage v. Temperature

As the voltage varied to the refrigerator, a vast range of temperatures could be recorded as seen in Figure 38. At 240V under the initial connection, 4.3°C was recorded. Throughout the testing, the refrigerator recorded the lowest temperature of 2.1°C at 237.6V and the highest temperature of 8.8°C at 229.2V. The lowest temperature deviated 51.6% from the initial state, with the highest temperature deviating 104.65% above the initial temperature.

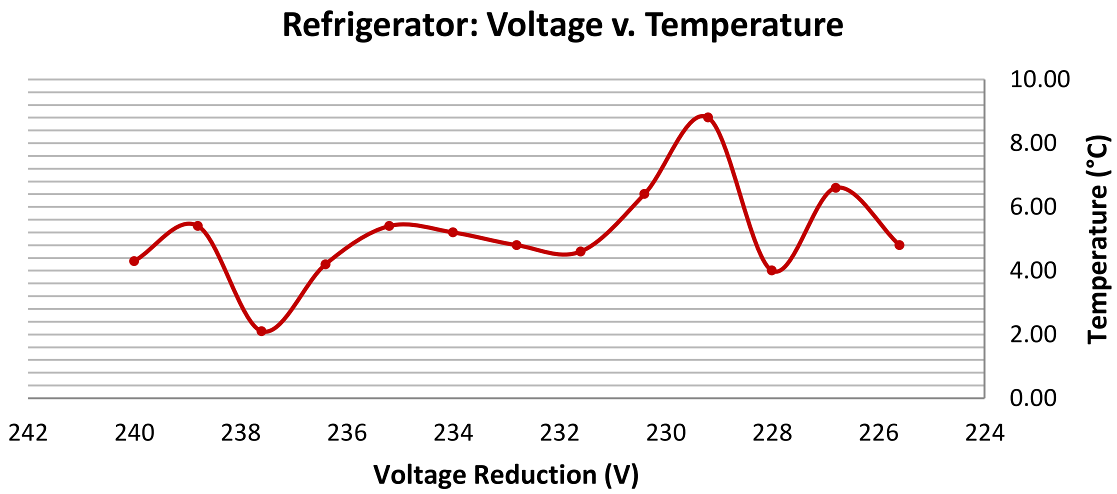

Figure 38 - Refrigerator: Voltage v. Temperature

3.5.6 Reduction Factor

The CVRf of the refrigerator, under reduced voltage conditions, provide a variety of results, as shown in Figure 39. With the voltage reduced by 0.5%, the efficiency increased presenting a Conservation Voltage Reduction factor of $CVRf = 3.77kWh$. The results heavily fluctuate, as the voltage is progressively reduced. At 235.2V the reduction factor reduced to $CVRf = -0.06$ and further reduced to $CVRf = -1.30$ at 229.2V.

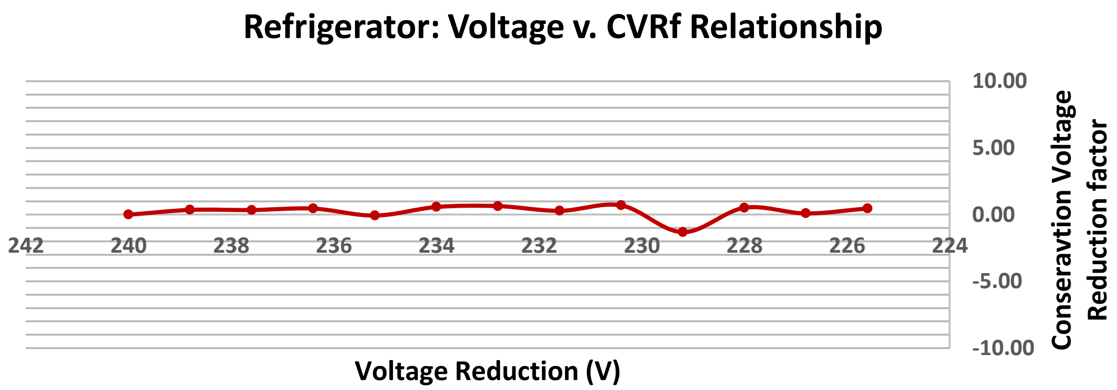

Figure 39 - Refrigerator: Voltage v. CVRf Relationship

3.6 Heating and Cooling Discussion

Considering all the above results, it can be concluded that the extent of the energy consumption reduction is truly dependant on the device itself and its mode of operation. The electric toaster, the energy reduction resulted in a significant reduction on the heating element temperature. The user would have to adjust the timer (Usually continuously adjustable) as to cook the toast a bit longer. May be more energy to brown the bread with a colder element. The kettles took longer to heat the water with the cooler heating element and the overall result was a use of more energy to heat or boil the water. The microwave proved to be a constant current type device presenting a reduced energy consumption, in the expected range of $CVRf = 1.0$. While the refrigerator behaved like a constant energy device since it contained a feedback control loop to maintain the temperature at the required value.

3.6.1 Electric Toaster Discussion

The electric toaster is an extremely simple device in both an operation and construction sense. With the device being, a constant resistive device, the toaster presents positive results when operated at all reduced voltages. Across all voltage decrements, a Conservation Voltage Reduction factor of >2.00 could be measured, while greater than >3.00 for both 0.5% and 1.0% voltage reductions. When operated at 2.0% / 235.2V the electric toaster only decreased 2.21% in temperature output, while the energy consumption resulted in a $CVRf = 2.57$.

The toaster’s runtime is determined by the dial setting on the device itself. Therefore, no matter how much the voltage is reduced, the time the device is operating remains constant. This constant time results in a significantly improved CVRf. However, should a slice of bread remain uncooked at the same time setting under reduced voltage conditions, the operating time would therefore require increasing, resulting in increased energy consumption and a hence reduced CVRf. Which is what will happen in practice as cooking times are constantly changed according to the type of bread or crumpet being toasted.

Figure 19 and Figure 20 do not correspond to the results expected from equation 2, as they show a linear relationship, as opposed to the expected quadratic realtionship. It can only be speculated, much like the incandescent lamp, the resistive heating element provides a slight variance in resistance as the temperature increases. With the temperature only decreasing by 7.58% from the initial 240V to the final reduced 225.6V, the reduction in temperature can be neglected simply because the energy saving is so great compared to the little reduction in temperature. Ultimately, the electric toaster has a reduced energy consumption, whilst operated at any of the 12 decreased voltage conditions.

3.6.2 Kettle Discussion

Like the above mentioned appliance, both electric kettles are contained within the same constant resistive category and essentially operate the same. With the heat output reducing with voltage, the time required to heat the water increases. The increased operation time prevents the CVRf from being consistent with what is expected with constant resistance devices, however an energy consumption reduction is seen for Kettle No.1.

Again at the modest 2.0% voltage reduction, kettle No.1 presents a CVRf of 0.29 (the largest recorded from this appliance). Additionally the time increases by a modest 3.87%, from 3.06 minutes to heat the water to 60°C to 3.18 minutes. A typical user may not even notice the small time increase and therefore would be fine to operate at this voltage level. However, operating for a longer duration would result in an increased energy consumption making the reduction in voltage unworthy of implementation.

Kettle No.2, however, provided no reduction in energy consumption for any decrement in voltage. Although power did decrease and therefore energy consumption decreased for a given moment, the kettle requires longer operating times in order to boil the same body of water. This increased operation time therefore outweighs the reduction in power draw resulting in an increase in energy consumption.

3.6.3 Microwave Discussion

The Microwave can be categorized as a constant current type load. Operating under reduced voltage conditions, the microwave's ability to heat water in a 3 minute time frame only decreased 8.8%, from 37.5°C to 34.2°C, this essentially enables any reduced voltage to be selected since a user would unlikely notice a 3.3°C change. Once again the 2.0% voltage reduction provides beneficial results. At 235.2V the microwave varied from it initially temperature output by 3.73%, additionally under this voltage the most efficient factor had been obtained, 1.19. Much like the above devices, all reduced voltage condition present increased efficiency; however, at 2.0% voltage reduction a compromise can be established between the microwaves operation and the increased efficiency / reduced energy consumption.

3.6.4 Refrigerator Discussion

The refrigerator falls into the constant energy category. As discussed in [3], constant energy devices, those appliances with feedback control do not provide reduced energy consumption under reduced voltage conditions. From the testing data, this could be disputed. However, a large number of factors reduce the accuracy of the results. The only available fridge to be tested for long periods of time was a personal appliance, which was utilized throughout testing. This resulted in its use becoming an additional factor. Changing ambient temperatures outside the fridge, additional humidity and similar factors affect the results slightly.

As the fridge cycles at irregular times, the internal fridge temperature greatly varies. Often the temperature was recorded when the device had not yet cycled on providing higher temperature readings. Other times, the fridge was currently operating providing a greatly reduced temperature. As a whole from the results taken, the fridge did not attain a drastically high temperature.

From the results it can be concluded, under reduced voltage conditions the device still operates correctly and temperature range remains that in the same region. However, additional testing with a power tracker would be highly recommended to obtain the true characteristics of the fridge at the various reduced temperatures.

CHAPTER 4. Motor Appliances

4.1 AC Induction Motor

Ranging from simple to more complex devices, the AC motor is used in the majority of homes without the home owner even realising. Installed in devices such as ceiling fans, air-conditioners, blenders and vacuum cleaners, the AC motor is a device which is contained within a mixture of load types. The data seen below shows the operating conditions and efficiency of a typical AC induction motor whilst operated at a number of reduced voltage conditions.

4.1.1 Compromise

The AC motor has been adopted to perform such tasks as rotating fan blades, pumps and blender blades. In order for it to fulfil its task, the motor must rotate the shaft at a particular speed, this rotation of shaft speed is measured as rotations per minute or abbreviated to RPM. As the voltage supply to the motor is reduced, the shaft speed shall be measured using a RPM meter connected to the shaft itself. Large variations from the original operation speed (at 240V) is not desired, as this could result in the device not operating as originally intended.

4.1.2 Testing Procedure

As per all appliances, the AC induction motor shall be connected, as per the connection diagram shown in Figure 5. The motor shall be tested with an 18.95Nm torque applied to the rotor shaft as per Figure 40 and Equation 4. During each decrement in voltage the motors operating characteristics, power, energy, whilst operating for 5 minutes, current and rotor speed are measured, from which the motors Conservation Voltage Reduction factor can be calculated.

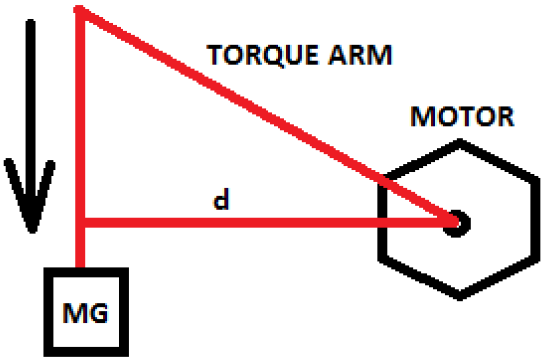

Figure 40 – Motor Torque Application

$$\tau = Fd = mgd$$ Equation 4

The motor setup allows for power factor correction, this shall remain on for the entire testing. It is important to note, although the device does in fact consume reactive power, as mentioned within the 'Load Types' section, the devices consumption of reactive power has not been considered. This assumption has been made to create simplicity and accuracy when testing their energy consumption.

4.1.3 Voltage v. Energy

From Figure 41, the AC induction motor can be observed to provide energy savings under reduced voltage conditions. Providing a downwards tread from the initial starting point, the motor consumed less energy for essentially every decrement in voltage. At 240V, when operated for 5 minutes continuously the appliance consumes 13.00Wh. As the voltage is reduced in 0.5% decrements, the energy consumption falls to 12.50Wh, 3.85% less energy at 3% reduction and has the lowest energy consumption of 11.60Wh, a 10.77% reduction in energy consumption whilst operated at 225.6V or 6% voltage reduction (regulatory limit).

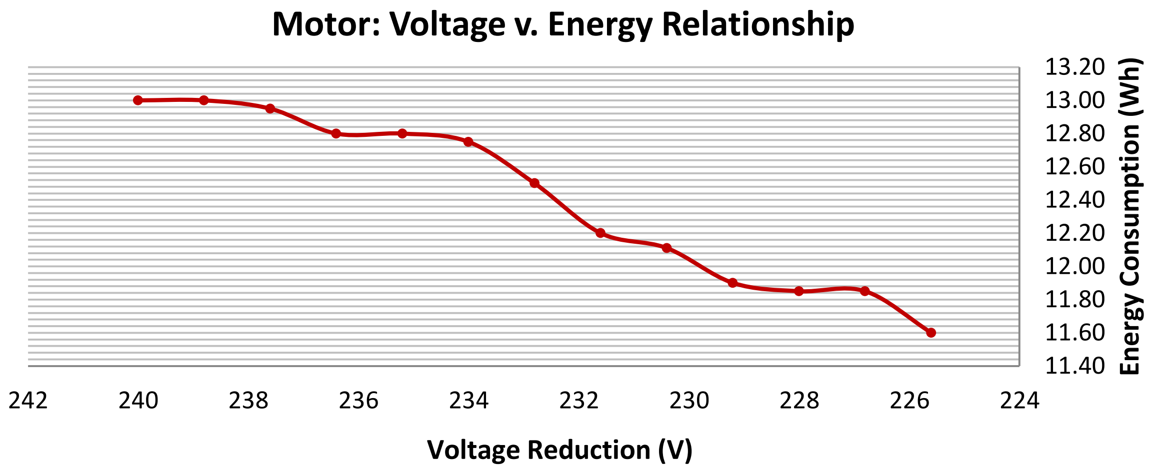

Figure 41 - Motor: Voltage v. Energy Relationship

4.1.4 Voltage v. Power

Instantaneous power consumption provides the basis of reduction in energy hence the downwards trend seen also in Figure 42. When operated at 240V the AC induction motor consumes an instantaneous power of 157.77W. As the voltage is reduced the motor consumes less power for each and every decrement. At 3% a slight dip can be observed, falling to 143.12W, 9.29% less power than initially. Finally at 6% reduction the power consumption resides at 133.14W presenting a 15.61% reduction on power compared to while operating 240V.

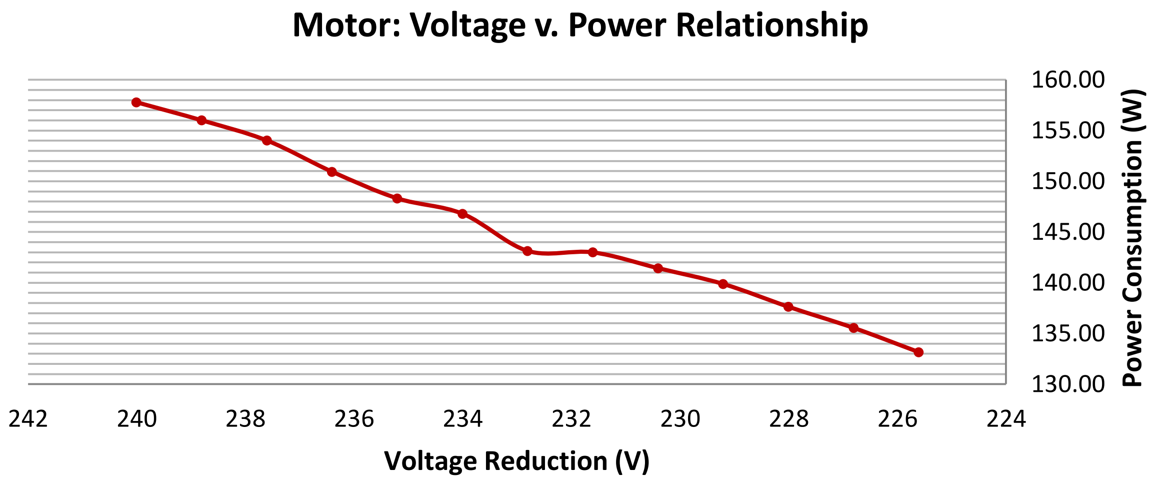

Figure 42 - Motor: Voltage v. Power Relationship

4.1.5 Voltage v. Rotations/min (RPM)

Across the complete range of voltage reduction, the AC induction motor can be observed to provide fluctuating results, as shown in Figure 43. When supplied with 240V, the average motor speed recorded was 1631.10RPM, when the voltage was reduced to 0.5% the rotor speed fell to 1626.9RPM before increasing to 1649.50RPM with a 1% voltage reduction. From the 1% voltage reduction, the motor gradually decreases to 1626.7RPM at 4% voltage reduction before once again spiking to a high 1673.50RPM at 5%.Towards the lower voltage limits, dropping to 1645.90RPM at 5.5% before operating at the minimum regulatory voltage reduction limit of 6% with a motor speed of 1671.8RPM.

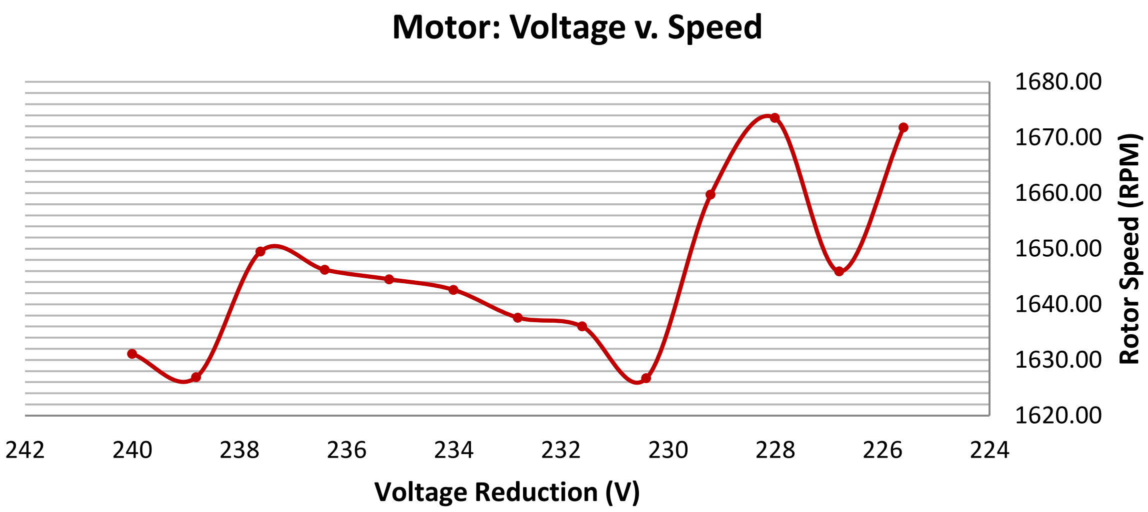

Figure 43 - Motor: Voltage v. Speed

4.1.6 Reduction Factor

Since the AC induction motor does not solely fit into a single load type, typical results as observed from devices such as the incandescent lamp or microwave oven, won't be seen. From Figure 44, the motor's energy consumption reduced when operated with reduced voltage conditions. From initial operation, the reduction factor increases to $CVRf = 1.03$ at 1.5% voltage reduction below 240V before declining to $CVRf = 0.77$ at both 2% and 2.5% of voltage reduction after the small dip, the motor steadily increases its CVRf to a high 1.76 at 3.5% of voltage reduction.

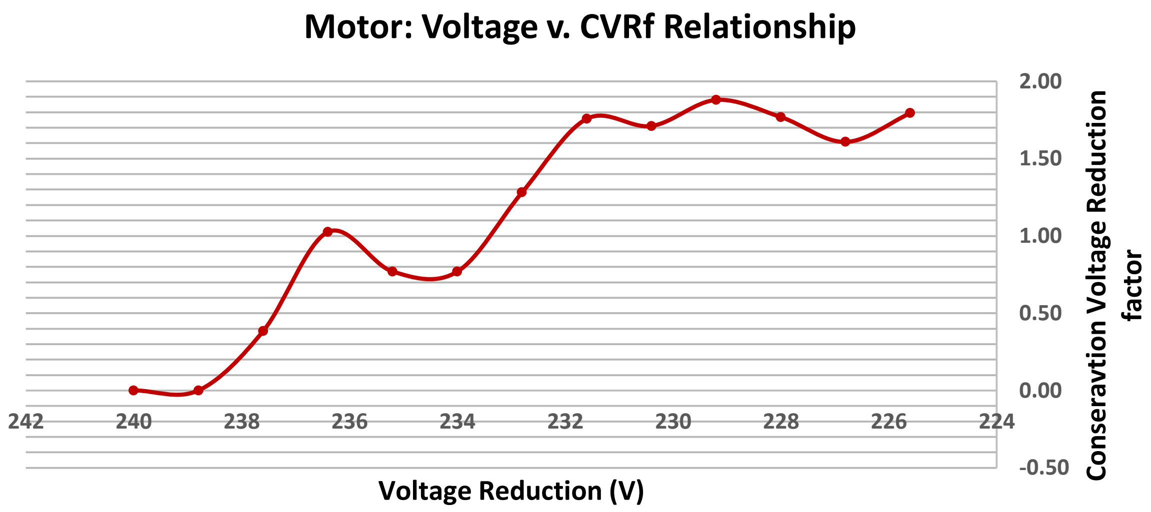

Figure 44 - Motor: Voltage v. CVRf Relationship

4.2 AC Induction Motor Discussion

Considering all the data measured from the thirteen voltage test percentages, the AC induction motor achieves reduced energy consumption whilst operated at voltages lower than the standard distributed 240V. However, depending on the load connected to the motor and the mode of control provided i.e Variable Speed Drive (VSD) or Direct Online (DO), energy consumption may be equal to that at 240V.

As the voltage is reduced, energy consumption decreased and the corresponding motor speed seemed to vary little, if any change occurred at all. The AC motor does not contribute to a large number of appliances in the home and would only provide a moderate saving in energy consumption on a large scale. Provided a modest 2.0% reduction in voltage was applied, a reduction factor of $CVRf = 0.77$ was obtained. However final operation and loading of the device will vary between appliances.

The air-condition could be assumed to operate for at least 12 hours a day during the cooler and hotter periods of the year. However, most air conditioners operate using thermal controllers, thermostats installed within the home to regulate temperatures. As discussed in [3], when containing a feedback loop, devices such as air-conditioners do not provide savings in energy consumption at reduced voltages. Although the device output is slightly reduced from the decreased voltage, the time required to reduce a room temperature to the desired level increases, ultimately consuming an equal amount of energy to the normal voltage scenarios.

CHAPTER 5. Electronic Device

5.1 Switch Mode Power Supply

The switch mode power supply is implemented in such devices as mobile phone chargers and personal computers. These devices allow incoming voltages to be regulated to achieve specific tasks. For instance, personal computers can operate over a large number of supply voltages. The switch mode power supply (SMPS) regulates the various internal DC voltages required by the internal circuiting.

5.1.1 Compromise

Unlike all the other devices tested, the Switch Mode Power Supply does not present a compromising factor to measure. The device could be tested while connected to a computer, however this could potentially damage expensive components within the PC.

5.1.2 Testing Procedure

The SMPS shall be tested under two conditions, ‘no load’ and ‘load’ conditions. Under no load conditions, the Switch Mode power supply is connected, as per the Figure 5 and tested, whilst no load is connected across the output. During the second test a 100Ω resistive load shall be connected across the output terminals. Both modes of operation shall be connected, as per the Figure 5, where the instantaneous power, current, voltage and energy consumption over a 10 minute period shall be measured.

5.1.3 Voltage v. Energy

Observing the energy consumption with respect to a reduction in voltage, while the Switch Mode Power Supply is operated under no load conditions, produced the results that can be seen plotted in Figure 45. Under this condition, the energy consumption is directly attributed to the circuitry contained within the appliance, given no load is connected across the terminals. At 240V the SMPS consumes 0.55Wh. Varying the voltage, the minimum power consumption was measured at 0.52Wh with the voltage set at 230.4V. The highest energy consumption, 0.55Wh, could be measured during nine various voltage instances. These recorded no load values are very low and potentially attributed to noise from the switch mode power supply.

Next referring to Figure 46, the loaded condition of the SMPS can be observed. With a 100Ω resistor connected across the devices terminals, the highest energy consumption recorded could be observed over six different voltage instances. The minimum energy consumption for the loaded scenario was measured at 1.88Wh whilst operating at 232.8V.

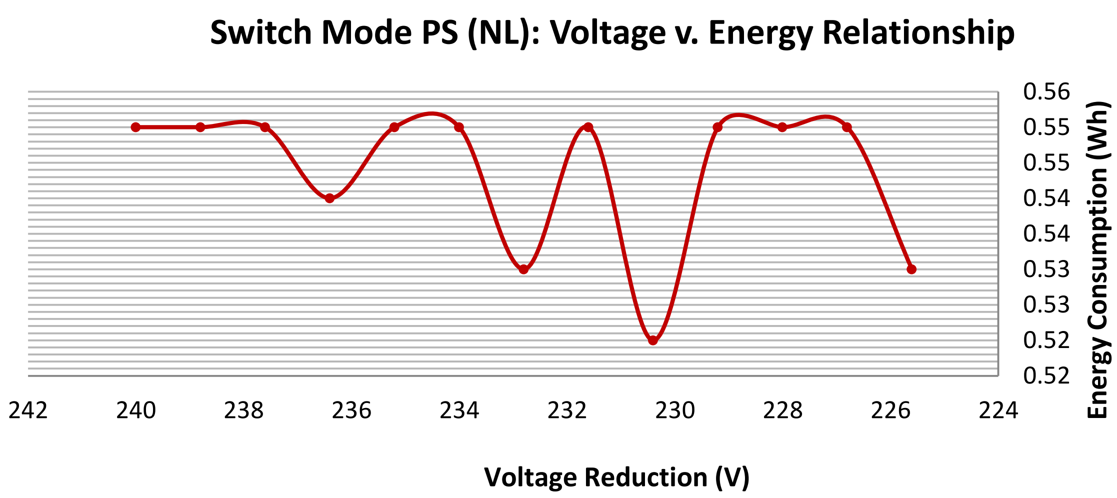

Figure 45 - Switch Mode PS (NL): Voltage v. Energy Relationship

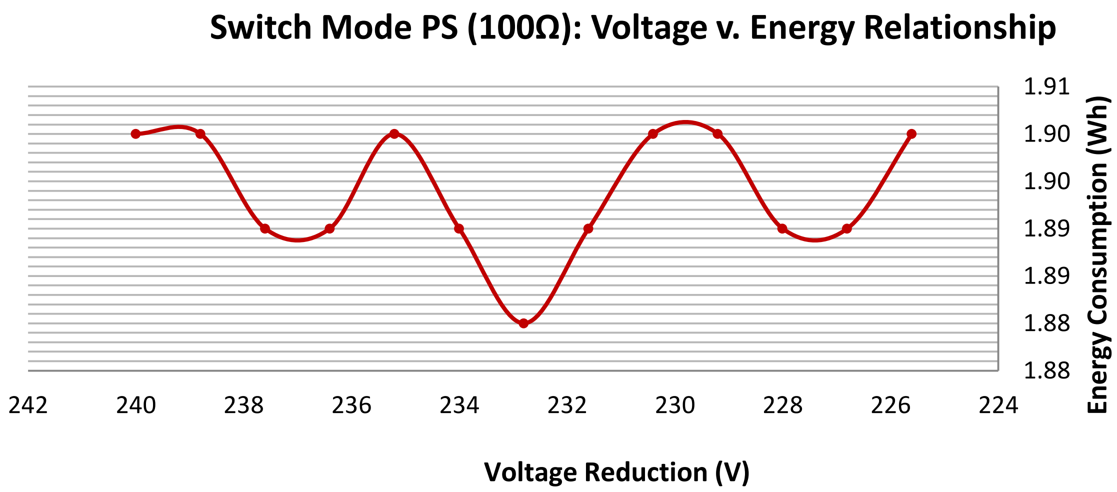

Figure 46 - Switch Mode PS (100Ω): Voltage v. Energy Relationship

5.1.4 Voltage v. Power

With the Switch Mode Power Supply operating with no load connected, the power consumption seen is that simply absorbed by the device itself. Figure 47 shows the change in instantaneous power consumption as the variac is adjusted changing the voltage. Initially consuming 3.15W at 240V, the power can be seen to fluctuate to a high of 3.17W at 236.7V and fall to 3.11W during four various voltage instances.

Connecting the resistor across the terminals, the graph seen in Figure 48 shows the instantaneous power starting at 11.68W. As the voltage is reduced in 0.5% voltage decrements, the power can be observed to fluctuate about the starting high 11.68W and the lowest recorded power consumption, 11.46W at 226.8V.

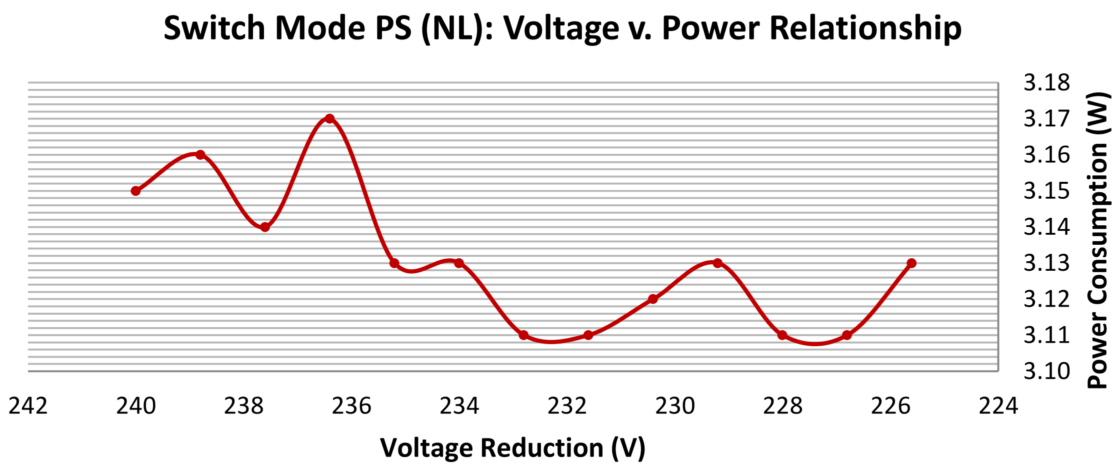

Figure 47 - Switch Mode PS (NL): Voltage v. Power Relationship

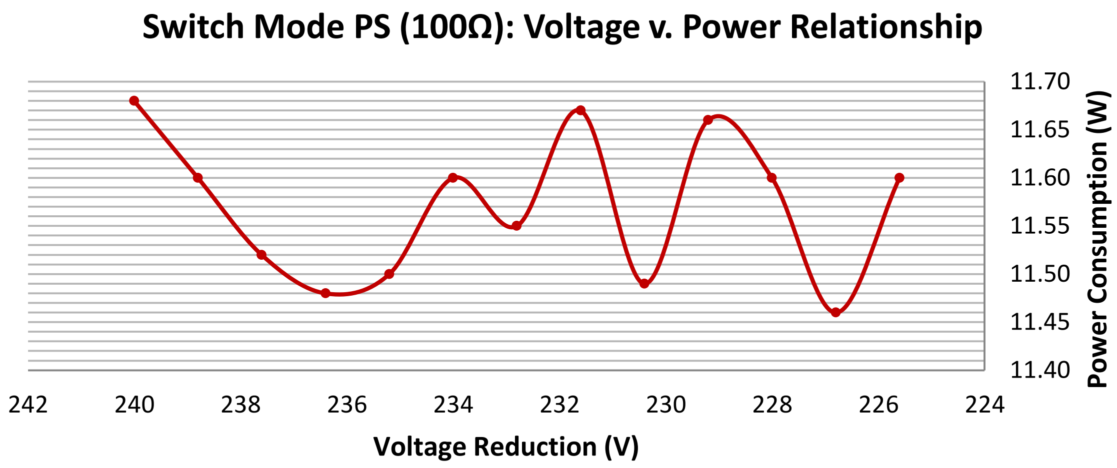

Figure 48 - Switch Mode PS (100Ω): Voltage v. Power Relationship

5.1.5 Reduction Factor

As the voltage is reduced to the Switch Mode Power Supply the results show in Figure 49 and Figure 50 were obtained. In Figure 49, which is for unloaded condition, It can be seen as the voltage is gradually reduced from the starting 240V to the final level of 225.6V, the reduction factor fluctuates. Under nine different voltage conditions, the efficiency of the appliance remained unchanged, which corresponded with previous research paper [3]. However, at 236.4V and 232.8V a reduction factor of 1.21 was obtained. Additionally at 230.4V, the energy consumption reduced and a conservation voltage reduction factor of 1.36 was measured.

For the loaded condition shown in Figure 50, the SMPS presented similar results to the unloaded condition, giving a CVRf of around 0.0, whilst presenting some spikes at various voltage conditions. At five voltage states, the energy consumption remained unchanged resulting in a reduction factor of 0.0. At 237.6V and 232.8V, the energy consumption decreased slightly, resulting in a reduction factor of 0.53.

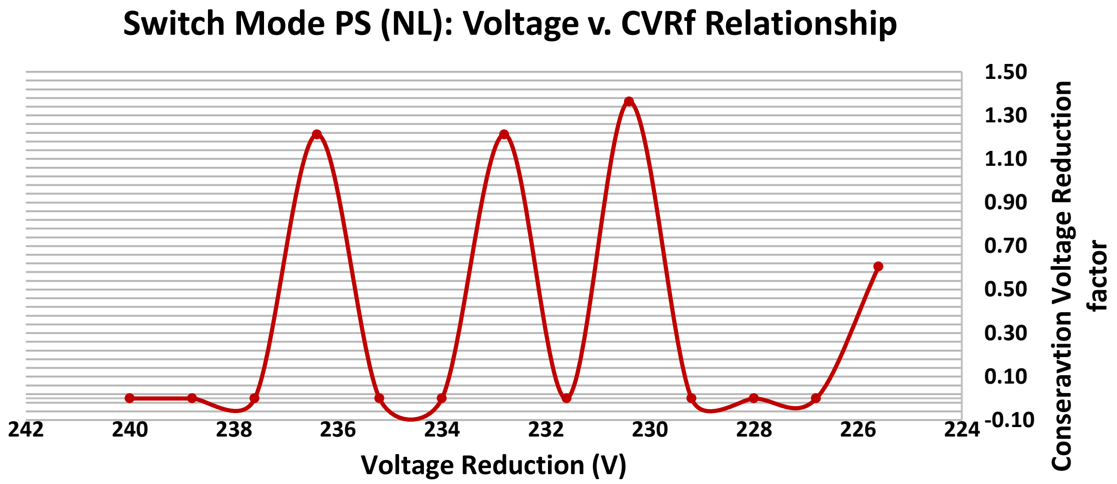

Figure 49 - Switch Mode PS (NL): Voltage v. CVRf Relationship

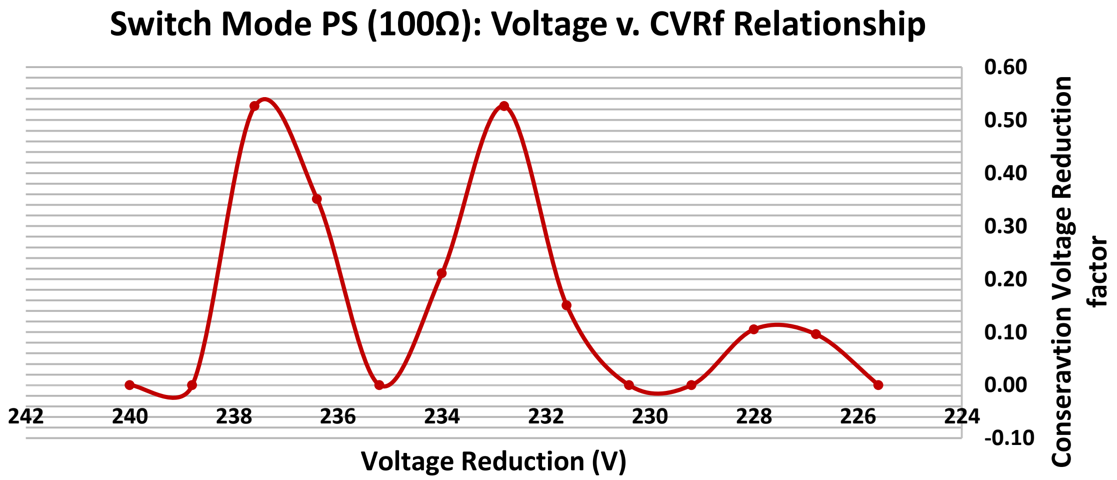

Figure 50 - Switch Mode PS (100Ω): Voltage v. CVRf Relationship

5.2 Electronic Device Discussion

From the Conservation Voltage Reduction factor plots (Figure 47 - Figure 50) it becomes clear that the Switch Mode Power Supply does not reduce its energy consumption under reduced voltage conditions. Categorized in the constant power load type, the SMPS, when operated under both no load and loaded did not indicate a significant energy saving. However, the difference is only great since the initial power is so small. Based on findings for both operating condition it is recommended that further testing be undertaken with loads closer to maximum load, or neglect these appliances when considering energy savings.

CHAPTER 6. Modelling

6.1 Single House Model

This single home model, developed under both reduced voltage and standard voltage conditions demonstrates the potential energy consumption savings able to be obtained through implementing Conservation Voltage Reduction. It is important to note, from all the devices that have been tested, only a model based on actual tested devices tested can be analysed. Additional accuracy can be obtained from the testing of devices such as air conditioning units, personal computers and televisions. The house model shall be structured to incorporate all the devices tested. Furthermore, the assumptions in section 6.4 are educated assumptions only and will vary from house to house. The single house model shall be structured around the standard 240V and with a reduction of 2.0%, 235.2V.

From Figure 51 below, Conservation Voltage Reduction can be seen to achieve reduced energy consumption. Comparing the initial total power consumption, to the final total power consumption the tested home model initially consumes 7413.2Wh and reduces to 7290.9Wh, providing a 1.68% reduction in energy consumption when each device is operated for the same time as during the testing. Based on these findings, given only a small reduction in energy consumption is obtained, implementing CVR would not be a viable option. The costs of installing such equipment to read, regulate and maintain the voltage at a reduced value would outweigh the avoided costs of energy saved.

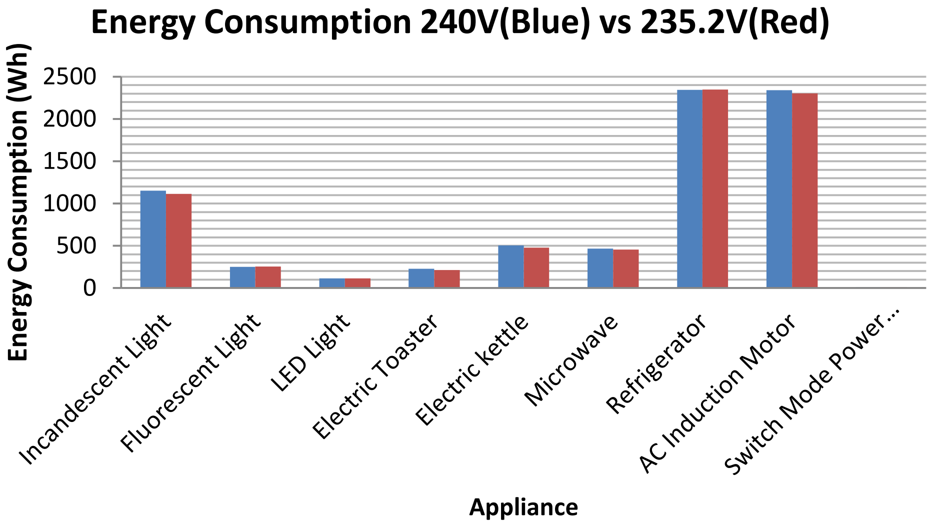

Figure 51 - Energy Consumption 240V(Blue) vs 235.2V(Red)

Figure 52, obtained from [16], presents a breakdown of electricity consumption by load category, within Australia during 2007. From this graph, it can be seen that constant current and constant resistance devices, the devices providing the greatest energy consumption savings, only make up a small portion of electrical energy consumed within the typical Australian home. For this reason, again Conservation Voltage Reduction would not be viable should it be provided to a single home.

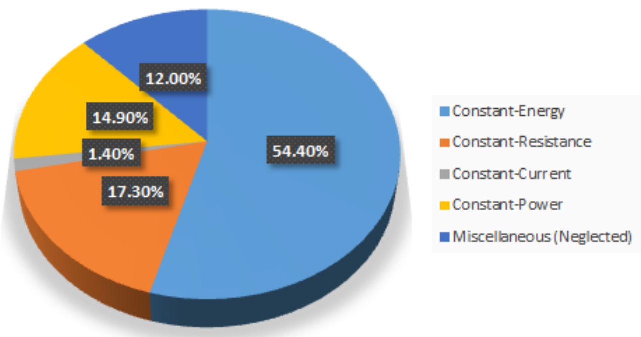

Figure 52 - Breakdown of the 2007 Australian residential electricity consumption by load category [16]

6.2 Large Scale Model

From a single house model alone, CVR would not be a viable option if only a 1.68% reduction in energy consumption would be achieved. Should Conservation Voltage Reduction be implemented on a large scale, the amount of energy saved could provide sufficient reasoning to adopt voltage reduction. The large scale model below shows a general LV distribution network, a typical Western Power distribution transformer could supply hundreds of homes. Should a reduced voltage be supplied to the network by changing the tap position on the distribution transformer, energy consumption reduction may be viable.

Observing Figure 53, a simulated large scale network can be seen containing four LV distribution feeders. Each distribution feeder is supplying homes with the typical 240V supply. At this voltage level this entire network, consisting of 100 homes consumes 741.34kWh, during a single day, whilst operating under the same assumptions as the single house model.

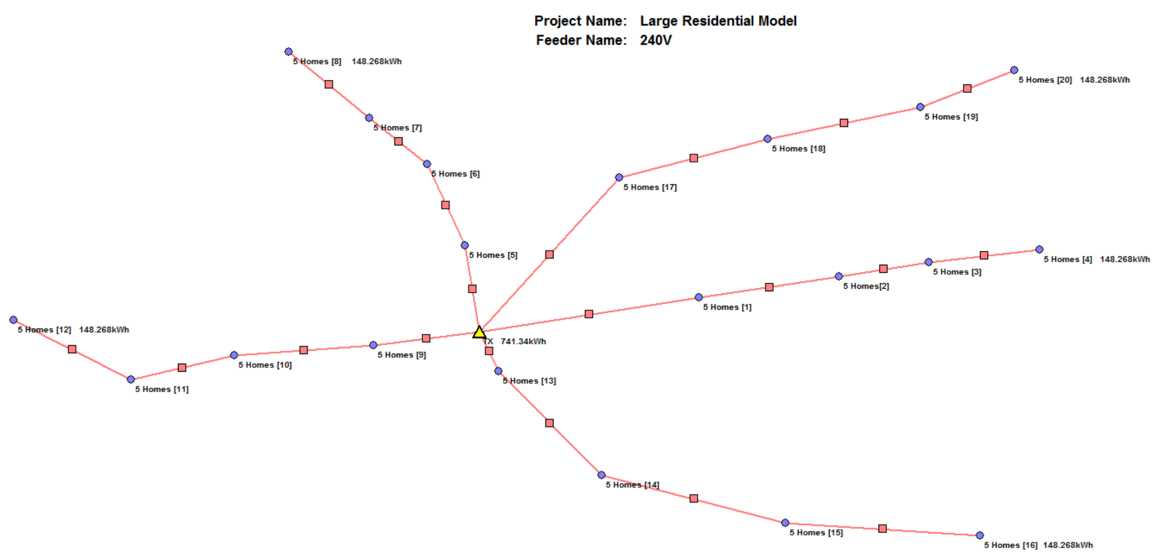

Figure 53 - Simulated Large Network at 240V

Referring to Figure 54, the same network can be seen, however the network is operating with the same assumptions as the single household model. With a 2.0% voltage reduction applied to the four LV distribution feeders, the energy consumption can be seen to significantly decrease. Initially consuming 741.34kWh, the network now consumes 729.1kWh during a single day, 12.25kWh less.

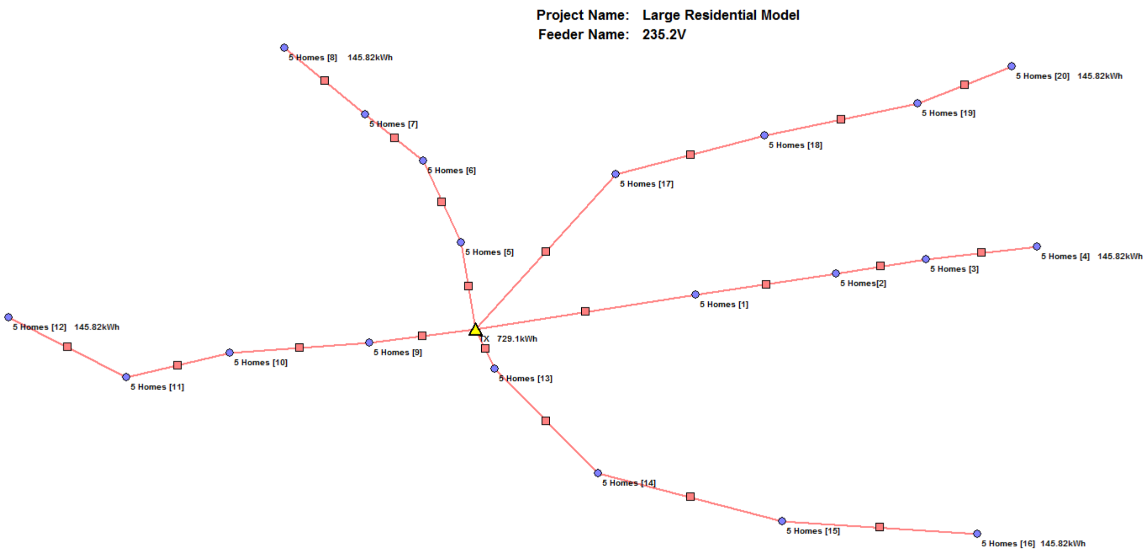

Figure 54 - Simulated Large Network at 2.0% Reduction

Although a 1.68% saving is still presented, when applied on a large scale, the absolute quantity of energy saved, results in less fossil fuels consumed to produce the energy and each home receives a small cost saving.

6.3 Cost Savings

Should Conservation Voltage Reduction be implemented, home owners could expect reduced energy bills as a result of reduced energy consumption. Figure 55, Figure 56 and Figure 57 outline the current Synergy A1 flat tariff and 'smart power' time of use rates within the south-west of Western Australia. It should be noted that 1 unit corresponds to 1kWh or 1000Wh. Figure 55 outlines the smart power rate per unit for a weekend day, all year round. Figure 56, the per unit for week days falling within the months of October to March and finally Figure 57, provides smart power rate per unit for weekdays during April to September. However, most customers are still on the flat A1 tariff of 25.7029 cents/unit.

Combined with the assumption made in the single house model, further assumptions have been made to determine where the devices commonly operate. For example, the refrigerator is operating continuously and the energy consumption shall be distributed over the complete day to accurately quantify the cost to operate the device over a complete year. The calculations have been based on the home operating at the standard 240V voltage and with Conservation Voltage Reduction implemented at 2.0%. Assumptions can be seen completely tabulated within Appendix J – Cost Savings

The test case house can be seen to initially consume 2684.12 units per year, costing $730.84. Reducing the voltage by 2.0%, the same modelled home would consume 2673.84 units per year at a reduced cost of $729.03. Keeping in mind these values are a result of the tested devices only, actual units consumed could be more or less depending on the quantity of devices being operated within the home.

From these cost savings it would be easy to write off Conservation Voltage Reduction as not worthy of implementation. However, these small cost savings could be obtained from a once off adjustment to the distribution transformer supplying the home. Furthermore the above assumptions and calculations neglect the use of some extremely high use devices such as personal computer, televisions, electric water heating, electric space heating, and electric stoves and ovens. From Figure 52, the combined constant current and constant resistive type loads only make up 18.7% of the typical homes energy consumption, hence the savings in costs are not going to be outstanding.

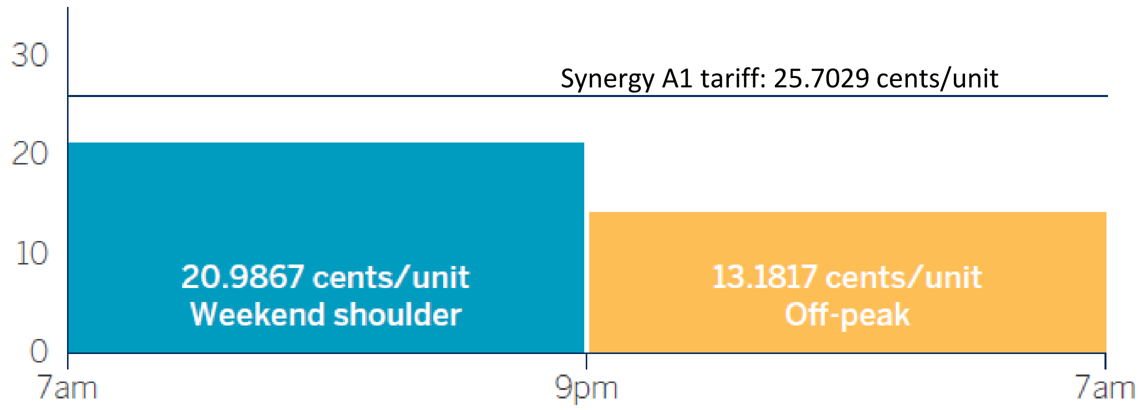

Figure 55 - Synergy Smart Power rate: Weekends all year round [17]

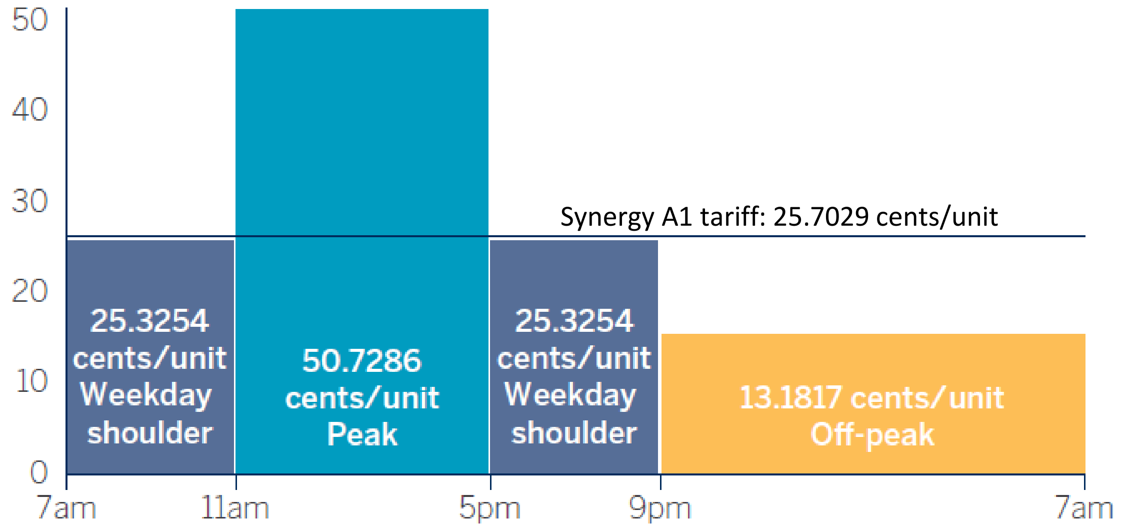

Figure 56 - Synergy Smart Power rate: Summer (October to March) Weekdays [17]

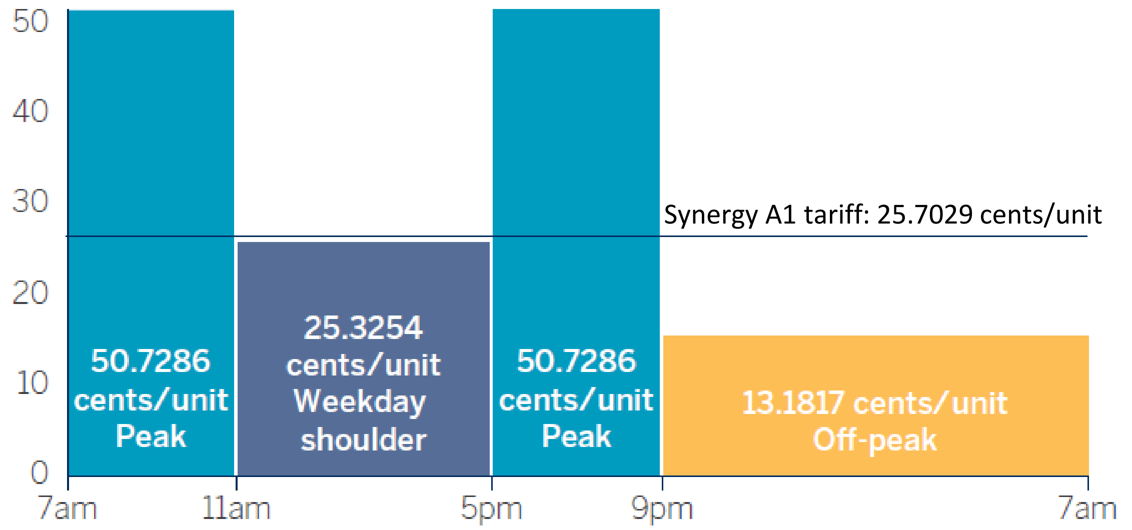

Figure 57 - Synergy Smart Power rate: Winter (April to September) Weekdays [17]

6.4 List of Model Assumptions

- Lighting appliances shall be operating for 720minutes/day.
- Each lighting type shall make up 1/3 of the lights operating.
- Kettle shall be run for a total of 15 minutes/day
- Toaster shall be operated for 15 minutes/day.
- The microwave shall operate for 30 minutes/day.
- The fridge shall be modelled as per the obtained data.
- A/C, blenders and fans shall be contained within the AC induction motor tests and shall be assumed to operate 900 minutes/ day.
- The Switch Mode power supply shall be considered to operate 60 minutes a day.

CHAPTER 7. Conclusion and Future Works

7.1 Conclusion

With the demand for energy rapidly increasing, methods of reducing energy consumption are becoming increasingly important. From the results obtained, implementing Conservation Voltage Reduction within the modern home would not prove to be a viable option. All modern household appliances can be categorised into the four load types, constant resistance, constant current, constant power and constant energy. Should a device not fall directly within a single load type, the appliance can be considered as a combination. The appliances tested under this thesis cover the majority of modern devices to be covered, e.g. fans and blenders under the AC inductions motor results and the various lighting types representing each type in use.

From the results obtained, it is clear that devices falling directly within the constant current and resistance load types provide the greatest decrease in energy consumption when operated under reduced voltage conditions. However, from Figure 52 it is understood that these load types only make up the minority of the modern homes, 18.7%. Should a 2.0% reduction be implemented on a single home the energy savings obtained would not provide sufficient reasoning to adopt CVR. On the other hand, if Conservation Voltage Reduction were to be implemented on a large scale, i.e. adjusting the transformer tap settings, the absolute energy consumption can be seen to significantly decrease from the simulation/model results. Widespread CVR implementation would provide quantifiable results and reduce the energy demand.

Each device tested presents a very different response to a reduction in voltage. However, combined with a reduction in energy consumption (for some appliances) a compromise has been established for each device;

With the Lighting appliances category the incandescent lamp and LED both reduced their energy consumption under reduced voltage conditions. However, total light output (depending on the amount of voltage reduced) must be compromised to obtain the increased efficiency. The Fluorescent lamp showed fluctuations in energy consumption, with no quantifiable energy reduction. The Fluorescent lamp, however, did not decrease in light output, but rather increased its light output at reduced voltages, speculated to be a result of increased current.

Similarly, heating and cooling devices all provided various results based on the appliances task and operation. The electric kettle, toaster and microwave all achieved a reduction in energy consumption, whilst operating at a lower voltage, again whilst compromising the appliance’s temperature output (which would lead to increased operating times resulting in no saving). It is recommended these appliances only operate at a mildly reduced voltage as to not deviate largely from the original output temperatures. The refrigerator provided no savings in energy as a result of its temperature control. The fridge would operate shorter or longer, more or less frequently, as required, resulting in the same energy consumption measured during original voltage conditions.

The AC induction motor exhibits a reduction in energy consumption whilst compromising little output speed, as a result of the voltage reduction. However, various different load connected to the motor and various starting methods, such as variable speed drive or direct on-line, could have negative impact on the overall energy consumption.

Tested to demonstrate the loading categories, the constant power Switch Mode Power Supply as expected and provided no considerable reduction in energy consumption with voltage reduction. Given these devices does not contribute to energy saving, It is not recommended that these devices be considered when deciding whether Conservation Voltage Reduction is viable, unless the reduction in voltage results in deviation due to a manufacturer’s design.

Concluding the above results devices contained within the constant resistance and constant current load types provided increased efficiency / minimised energy consumption when operated under reduced voltage conditions. Constant resistance load types typically provided a factor in the range of $CVRf = 2.0$, while constant current devices providing a factor in the range of $CVRf = 1.0$, corresponding to existing research [3] [11]. Constant power, constant energy and devices provided with feedback control, however, do not provide any reduction in energy consumption.

A voltage reduction of ≈2.0% provides quantifiable energy reduction when implemented on a large scale feeder as seen in the simulation and should provide a suitable compromise between each devices original operating characteristics (This is subject to the individual). Further reducing the voltage can provide additional savings, however as outlined earlier, each device adopts a compromise which must also be considered. Conservation Voltage Reduction can be utilized at the lower limit of regulatory voltage limits provided no discomfort is brought and occupants are elated with the devices operation.

From the obtained results it is understood that CVR does provide increase efficiency / reduced energy consumption predominantly for constant resistance and constant current devices, however for constant energy, constant power and appliances with feedback control, voltage reduction does not provide increased efficiency. This increased efficiency attributes to minor reduction in cost to the consumer while further reducing the overall demand for energy; hence minimizing the unnecessary consumption of fossil fuels.

7.2 Future Work

Results found from these research experiments do not cover the entirety of CVR's capabilities, as the title suggests, the research only covers Conservation Voltage Reduction implemented in household applications. Further development, within the field of voltage reduction, would serve to provide a clear understanding of the benefits of a reduction in voltage. Listed below are suggested items to further develop an understanding of the true capabilities of operating distribution networks at a reduced voltage.

Appliance lifespan – One huge potential of Conservation Voltage Reduction is the potential to provide increased lifespan to common household appliance. Testing appliances under reduced voltages for extended periods of time could be done to compare deterioration rates to that observed during normal operating conditions.

Extensive field testing – As outlined, each appliance is coupled with counterproductive compromises. i.e light intensity reducing with reduced voltage. To test the effects of these compromises, extensive field testing can provide direct feedback on how the reduced voltage effects an individual. One potential test to perform would be to have 5 houses operating under a reduced voltage condition and 5 houses operating at the standard 240V - a control group and an experimental group. The test would be conducted without the occupants knowing knowing which house they will be living in, with each occupant reporting back with their experience and whether they thought the house was operating at a lower voltage or not.

Testing expensive electronic equipment – Due to financial restraints there has been no opportunity to test expensive electronic appliances, such as computers and TVs. Should such devices be available, it would be highly recommended these devices are tested in the same conditions as the appliances listed in this research paper.

Fixed voltage conditions- Voltage from the typical general power outlet experiences fluctuations depending on a number of variables, such a loading on the circuit. This provides slight inconsistencies in the results obtained, although the tests provided a clear understanding of reduced energy consumption arising from reduced voltages. The data obtained could be far more accurate with a voltage regulated output. It is recommended for additional accuracy each device be tested, whilst the supply voltage is regulated to a constant voltage removing all fluctuations.

Voltages at various home locations – With each and every home, the output voltage from the general power outlets is slightly different. As such, the amount of voltage reduction to be implemented through CVR varied from case to case. Further research should be undertaken to determine the average house voltage under various condition. That is, determine the average voltage for the following cases;

- Close to and far from transformers
- Close to and far from generators
- Highly loaded network feeders
- Light loaded network feeders
- Various area codes

From this information a clear understanding would be gained on how much voltage reduction could be implemented in each case.

Impact – When Conservation Voltage Reduction is implemented, what impact is exerted on the existing network? Will existing transmission and distribution cables be able to handle these conditions? Further research and development should be undertaken to obtain a complete understanding of the repercussions of voltage reduction.

Reactive element- Design circuit models of each appliance with a variable voltage to show CVR working. This is an easy task for simple devices such as the kettle and toaster, however more complex devices such as the fluorescent lamps, microwave ovens and motors require further analysis. Obtaining the reactive power characteristics for each device would allow these more complex devices to be modelled as an equivalent RLC (Resistive, Capacitive and Inductive) circuit.

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Appendices

Appendix A - Incandescent Lamp

Table 1 - Incandescent Lamp Detailed Results

Incandescent Light												
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (mA)	ΔI(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time	Light Intensity (LUX)	LUX Decrease (%)	CVRf
240.0	0.0%	92.50	0.00%	385.66	0.00%	16.00	15.42	0.00%	Operated for precicelly 10 minutes.	381	0.00	0.00
238.8	0.5%	91.80	0.76%	384.80	0.22%	15.80	15.30	0.76%		376	-1.31	1.51
237.6	1.0%	90.98	1.64%	383.32	0.61%	15.60	15.16	1.64%		366	-3.94	1.64
236.4	1.5%	90.27	2.41%	382.37	0.85%	15.55	15.05	2.41%		360	-5.51	1.61
235.2	2.0%	89.66	3.07%	381.27	1.14%	15.46	14.94	3.07%		354	-7.09	1.54
234.0	2.5%	88.86	3.94%	380.55	1.33%	15.40	14.81	3.94%		347	-8.92	1.57
232.8	3.0%	88.09	4.77%	379.10	1.70%	15.32	14.68	4.77%		339	-11.02	1.59
231.6	3.5%	88.11	4.75%	379.37	1.63%	15.10	14.69	4.75%		331	-13.12	1.36
230.4	4.0%	86.99	5.96%	377.59	2.09%	15.05	14.50	5.96%		325	-14.70	1.49
229.2	4.5%	86.31	6.69%	376.64	2.34%	14.90	14.39	6.69%		318	-16.54	1.49
228.0	5.0%	85.74	7.31%	375.81	2.55%	14.90	14.29	7.31%		310	-18.64	1.46
226.8	5.5%	84.94	8.17%	374.58	2.87%	14.76	14.16	8.17%		305	-19.95	1.49
225.6	6.0%	84.01	9.18%	373.26	3.22%	14.44	14.00	9.18%		296	-22.31	1.53

Appendix B – Fluorescent Lamp

Table 2 - Fluorescent Lamp Detailed Results

Fluorescent Light												
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (mA)	ΔI(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time	Light Intensity (LUX)	LUX Decrease (%)	CVRf
240.0	0.0%	21.18	0.00%	168.47	0.00%	3.50	3.53	0.00%	Operated for precicelly 10 minutes.	709	0.00	0.00
238.8	0.5%	20.80	1.79%	168.77	-0.18%	3.52	3.47	-0.57%		739	4.23	-1.14
237.6	1.0%	20.91	1.27%	169.55	-0.64%	3.50	3.49	0.00%		770	8.60	0.00
236.4	1.5%	20.82	1.70%	170.98	-1.49%	3.50	3.47	0.00%		783	10.44	0.00
235.2	2.0%	20.35	3.92%	168.52	-0.03%	3.52	3.39	-0.57%		798	12.55	-0.29
234.0	2.5%	20.61	2.69%	173.47	-2.97%	3.49	3.44	0.29%		804	13.40	0.11
232.8	3.0%	20.85	1.56%	172.01	-2.10%	3.48	3.48	0.57%		775	9.31	0.19
231.6	3.5%	20.82	1.70%	172.28	-2.26%	3.51	3.47	-0.29%		780	10.01	-0.08
230.4	4.0%	20.45	3.45%	171.86	-2.01%	3.51	3.41	-0.29%		794	11.99	-0.07
229.2	4.5%	20.28	4.25%	170.01	-0.91%	3.52	3.38	-0.57%		795	12.13	-0.13
228.0	5.0%	20.14	4.91%	170.46	-1.18%	3.50	3.36	0.00%		795	12.13	0.00
226.8	5.5%	19.88	6.14%	168.93	-0.27%	3.50	3.31	0.00%		782	10.30	0.00
225.6	6.0%	20.24	4.44%	171.86	-2.01%	3.49	3.37	0.29%		772	8.89	0.05

Appendix C – Light Emitting Diode

Table 3 - Light Emitting Diode Detailed Results

LED Light												
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (mA)	ΔI(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time	Light Intensity (LUX)	LUX Decrease (%)	CVRf
240.0	0.0%	9.46	0.00%	42.60	0.00%	1.60	1.58	0.00%	Operated for precicelly 10 minutes.	213	0.00	0.00
238.8	0.5%	9.40	0.63%	42.50	0.23%	1.58	1.57	0.63%		211	-0.94	1.27
237.6	1.0%	9.34	1.27%	42.46	0.33%	1.57	1.56	1.27%		209	-1.88	1.27
236.4	1.5%	9.31	1.59%	42.39	0.49%	1.57	1.55	1.59%		208	-2.35	1.06
235.2	2.0%	9.27	2.01%	42.32	0.66%	1.57	1.55	2.01%		207	-2.82	1.00
234.0	2.5%	9.23	2.43%	42.35	0.59%	1.55	1.54	2.43%		206	-3.29	0.97
232.8	3.0%	9.19	2.85%	42.32	0.66%	1.55	1.53	2.85%		204	-4.23	0.95
231.6	3.5%	9.13	3.49%	42.22	0.89%	1.55	1.52	3.49%		203	-4.69	1.00
230.4	4.0%	9.10	3.81%	42.23	0.87%	1.53	1.52	3.81%		202	-5.16	0.95
229.2	4.5%	9.08	4.02%	42.21	0.92%	1.53	1.51	4.02%		202	-5.16	0.89
228.0	5.0%	9.01	4.76%	42.19	0.96%	1.52	1.50	4.76%		200	-6.10	0.95
226.8	5.5%	8.99	4.97%	42.18	0.99%	1.52	1.50	4.97%		200	-6.10	0.90
225.6	6.0%	8.94	5.50%	42.18	0.99%	1.52	1.49	5.50%		199	-6.57	0.92

Appendix D – Electric Toaster

Table 4 - Electric Toaster Detailed Results

Toaster												
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (A)	ΔI(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time	Temperature (°C)	Temperature Decrease (%)	CVRf
240.0	0.0%	907.23	0.00%	3.81	0.00%	15.00	15.12	0.00%	Operated for precicelly 60 seconds (Dial setting 1) as to avoid heat damage to the device.	488.90	0.00	0.00
238.8	0.5%	891.22	1.76%	3.79	0.52%	15.00	14.85	1.76%		487.10	-0.37	3.53
237.6	1.0%	875.26	3.52%	3.75	1.57%	14.80	14.59	3.52%		484.40	-0.92	3.52
236.4	1.5%	870.01	4.10%	3.72	2.36%	14.70	14.50	4.10%		483.90	-1.02	2.74
235.2	2.0%	860.6	5.14%	3.69	3.15%	14.30	14.34	5.14%		478.10	-2.21	2.57
234.0	2.5%	850.63	6.24%	3.67	3.67%	14.20	14.18	6.24%		476.10	-2.62	2.50
232.8	3.0%	841.93	7.20%	3.65	4.20%	14.15	14.03	7.20%		472.90	-3.27	2.40
231.6	3.5%	830.02	8.51%	3.62	4.99%	14.00	13.83	8.51%		466.40	-4.60	2.43
230.4	4.0%	824.51	9.12%	3.61	5.25%	13.90	13.74	9.12%		463.60	-5.17	2.28
229.2	4.5%	814.49	10.22%	3.59	5.77%	13.70	13.57	10.22%		456.30	-6.67	2.27
228.0	5.0%	809.17	10.81%	3.57	6.30%	13.60	13.49	10.81%		456.00	-6.73	2.16
226.8	5.5%	799.02	11.93%	3.55	6.82%	13.40	13.32	11.93%		456.00	-6.73	2.17
225.6	6.0%	780.13	14.01%	3.51	7.87%	13.10	13.00	14.01%		454.00	-7.14	2.33

Appendix E - Kettle

Table 5 – Kettle No.1 Detailed Results

Kettle No.1											
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (A)	Δi(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time (Minutes)	Time Increase (%)	CVRf
240.0	0.0%	2001.28	0.00%	8.48	0.00%	101.80	102.07	0.00%	3.06	0.00	0.00
238.8	0.5%	1990.22	0.55%	8.46	0.24%	103.20	103.60	-1.51%	3.12	2.07	-3.01
237.6	1.0%	1959.66	2.08%	8.42	0.71%	103.80	103.86	-1.76%	3.18	3.92	-1.76
236.4	1.5%	1936.95	3.21%	8.37	1.30%	101.80	102.01	0.05%	3.16	3.27	0.03
235.2	2.0%	1915.58	4.28%	8.32	1.89%	101.70	101.47	0.58%	3.18	3.87	0.29
234.0	2.5%	1906.32	4.74%	8.29	2.24%	103.40	103.58	-1.48%	3.26	6.54	-0.59
232.8	3.0%	1886.15	5.75%	8.26	2.59%	105.10	104.63	-2.51%	3.33	8.77	-0.84
231.6	3.5%	1862.33	6.94%	8.20	3.30%	103.70	103.51	-1.42%	3.34	8.99	-0.41
230.4	4.0%	1855.91	7.26%	8.18	3.54%	106.00	106.46	-4.30%	3.44	12.47	-1.08
229.2	4.5%	1823.71	8.87%	8.13	4.13%	104.20	104.31	-2.20%	3.43	12.15	-0.49
228.0	5.0%	1794.26	10.34%	8.07	4.83%	104.00	102.97	-0.89%	3.44	12.53	-0.18
226.8	5.5%	1793.18	10.40%	8.06	4.95%	102.40	102.56	-0.48%	3.43	12.15	-0.09
225.6	6.0%	1770.52	11.53%	8.00	5.66%	102.00	102.40	-0.32%	3.47	13.40	-0.05

Table 6 – Kettle No.2 Detailed Results

Kettle No.2											
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (A)	Δi(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time (Minutes)	Time Increase (%)	CVRf
240.0	0.0%	2127.74	0.00%	9.00	0.00%	96.40	96.40	0.00%	2.72	0.00	0.00
238.8	0.5%	2103.97	1.12%	8.95	0.56%	101.70	101.98	-5.50%	2.91	6.99	-11.00
237.6	1.0%	2072.29	2.61%	8.88	1.33%	98.50	99.53	-2.18%	2.88	6.01	-2.18
236.4	1.5%	2063.11	3.04%	8.86	1.56%	100.00	100.40	-3.73%	2.92	7.42	-2.49
235.2	2.0%	2046.60	3.81%	8.83	1.89%	103.60	103.98	-7.47%	3.05	12.14	-3.73
234.0	2.5%	2023.48	4.90%	8.77	2.56%	100.80	101.62	-4.56%	3.01	10.85	-1.83
232.8	3.0%	1998.38	6.08%	8.72	3.11%	102.80	103.14	-6.64%	3.10	13.92	-2.21
231.6	3.5%	1983.79	6.77%	8.69	3.44%	101.10	101.72	-4.88%	3.08	13.18	-1.39
230.4	4.0%	1964.99	7.65%	8.64	4.00%	104.60	105.07	-8.51%	3.21	18.03	-2.13
229.2	4.5%	1937.85	8.92%	8.59	4.56%	105.50	105.67	-9.44%	3.27	20.36	-2.10
228.0	5.0%	1914.01	10.04%	8.53	5.22%	109.60	109.95	-13.69%	3.45	26.79	-2.74
226.8	5.5%	1880.48	11.62%	8.46	6.00%	105.70	106.19	-9.65%	3.39	24.65	-1.75
225.6	6.0%	1852.74	12.92%	8.39	6.78%	104.90	105.19	-8.82%	3.41	25.32	-1.47

Appendix F – Microwave

Table 7 - Microwave Detailed Results

Microwave													
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (A)	ΔI(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time	Temperature (°C)	Temperature Decrease (%)	CVRf
240.0	0.0%	937.50	0.00%	4.19	0.00%	46.60	46.88	0.00%	Operated for precicelly 180 seconds.	37.50	0.00	0.00
238.8	0.5%	932.30	0.55%	4.19	0.00%	45.90	46.62	0.55%		36.20	-3.47	1.11
237.6	1.0%	927.70	1.05%	4.18	0.24%	45.90	46.39	1.05%		38.00	1.33	1.05
236.4	1.5%	926.80	1.14%	4.20	-0.24%	45.80	46.34	1.14%		37.80	0.80	0.76
235.2	2.0%	915.20	2.38%	4.18	0.24%	45.40	45.76	2.38%		36.10	-3.73	1.19
234.0	2.5%	909.60	2.98%	4.19	0.00%	45.30	45.48	2.98%		36.20	-3.47	1.19
232.8	3.0%	911.40	2.78%	4.20	-0.24%	45.00	45.57	2.78%		36.80	-1.87	0.93
231.6	3.5%	903.60	3.62%	4.20	-0.24%	44.80	45.18	3.62%		36.20	-3.47	1.03
230.4	4.0%	900.35	3.96%	4.19	0.00%	44.50	45.02	3.96%		36.00	-4.00	0.99
229.2	4.5%	897.90	4.22%	4.19	0.00%	44.40	44.90	4.22%		34.90	-6.93	0.94
228.0	5.0%	892.70	4.78%	4.20	-0.24%	44.20	44.64	4.78%		34.50	-8.00	0.96
226.8	5.5%	890.50	5.01%	4.23	-0.95%	44.00	44.53	5.01%		35.00	-6.67	0.91
225.6	6.0%	881.70	5.95%	4.21	-0.48%	43.60	44.09	5.95%		34.20	-8.80	0.99

Appendix G – Refrigerator

Table 8 - Refrigerator Detailed Results

Refrigerator												
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (A)	ΔI(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time	Temperature (°C)	Temperature Decrease (%)	CVRf
240.0	0.0%	200.1	0.00%	1.35	0.00%	1172.70	This section cannot be calculated given runtime and run frequency are unknown.	0.00%	Device was left operating at all time.	4.30	0.00	0.00
238.8	0.5%	211.24	-5.57%	1.38	-2.22%	1170.60		0.18%		5.40	25.58	0.36
237.6	1.0%	208.85	-4.37%	1.38	-2.22%	1168.60		0.35%		2.10	-51.16	0.35
236.4	1.5%	176.1	11.99%	1.28	5.19%	1164.66		0.69%		4.20	-2.33	0.46
235.2	2.0%	183.33	8.38%	1.28	5.19%	1174.20		-0.13%		5.40	25.58	-0.06
234.0	2.5%	177.76	11.16%	1.27	5.93%	1155.80		1.44%		5.20	20.93	0.58
232.8	3.0%	181.23	9.43%	1.27	5.93%	1150.10		1.93%		4.80	11.63	0.64
231.6	3.5%	226.97	-13.43%	1.39	-2.96%	1160.80		1.01%		4.60	6.98	0.29
230.4	4.0%	183.74	8.18%	1.26	6.67%	1140.20		2.77%		6.40	48.84	0.69
229.2	4.5%	187.48	6.31%	1.27	5.93%	1241.50		-5.87%		8.80	104.65	-1.30
228.0	5.0%	174.64	12.72%	1.22	9.63%	1142.40		2.58%		4.00	-6.98	0.52
226.8	5.5%	177.89	11.10%	1.23	8.89%	1166.60		0.52%		6.60	53.49	0.09
225.6	6.0%	179.31	10.39%	1.24	8.15%	1140.00		2.79%		4.80	11.63	0.46

Appendix H – AC Induction Motor

Table 9 - AC Induction Motor Detailed Results

AC motor													
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (mA)	ΔI(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time	Rotor Speed (RPM)	Speed Variation (%)	CVRf
240.0	0.0%	157.77	0.00%	744.05	0.00%	13.00	13.15	0.00%	Operated for precicelly 5 minutes.	1631.10	0.00	0.00
238.8	0.5%	155.99	1.13%	734.80	1.24%	13.00	13.00	0.00%		1626.90	-0.26	0.00
237.6	1.0%	154.00	2.39%	733.17	1.46%	12.95	12.83	0.38%		1649.50	1.13	0.38
236.4	1.5%	150.92	4.34%	727.54	2.22%	12.80	12.58	1.54%		1646.20	0.93	1.03
235.2	2.0%	148.30	6.00%	725.38	2.51%	12.80	12.36	1.54%		1644.50	0.82	0.77
234.0	2.5%	146.78	6.97%	725.90	2.44%	12.75	12.23	1.92%		1642.60	0.71	0.77
232.8	3.0%	143.12	9.29%	724.47	2.63%	12.50	11.93	3.85%		1637.60	0.40	1.28
231.6	3.5%	142.98	9.37%	724.34	2.65%	12.20	11.92	6.15%		1636.00	0.30	1.76
230.4	4.0%	141.42	10.36%	719.52	3.30%	12.11	11.79	6.85%		1626.70	-0.27	1.71
229.2	4.5%	139.86	11.35%	723.18	2.80%	11.90	11.66	8.46%		1659.70	1.75	1.88
228.0	5.0%	137.61	12.78%	725.41	2.51%	11.85	11.47	8.85%		1673.50	2.60	1.77
226.8	5.5%	135.53	14.10%	727.98	2.16%	11.85	11.29	8.85%		1645.90	0.91	1.61
225.6	6.0%	133.14	15.61%	728.17	2.13%	11.60	11.10	10.77%		1671.80	2.50	1.79

Appendix I – Switch Mode Power Supply

Table 10 - Switch Mode Power Supply (No Load) Detailed Results

Switch Mode Power Supply (No Load)												
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (mA)	ΔI(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time	Light Intensity (LUX)	LUX Decrease (%)	CVRf
240.0	0.0%	3.15	0.00%	50.49	0.00%	0.55	0.53	0.00%	Operated for precicelly 10 minutes.	709	0.00	0.00
238.8	0.5%	3.16	-0.32%	49.06	2.83%	0.55	0.53	0.00%		739	4.23	0.00
237.6	1.0%	3.14	0.32%	51.00	-1.01%	0.55	0.52	0.00%		770	8.60	0.00
236.4	1.5%	3.17	-0.63%	49.39	2.18%	0.54	0.53	1.82%		783	10.44	1.21
235.2	2.0%	3.13	0.63%	48.87	3.21%	0.55	0.52	0.00%		798	12.55	0.00
234.0	2.5%	3.13	0.63%	48.84	3.27%	0.55	0.52	0.00%		804	13.40	0.00
232.8	3.0%	3.11	1.27%	50.41	0.16%	0.53	0.52	3.64%		775	9.31	1.21
231.6	3.5%	3.11	1.27%	50.14	0.69%	0.55	0.52	0.00%		780	10.01	0.00
230.4	4.0%	3.12	0.95%	49.89	1.19%	0.52	0.52	5.45%		794	11.99	1.36
229.2	4.5%	3.13	0.63%	50.17	0.63%	0.55	0.52	0.00%		795	12.13	0.00
228.0	5.0%	3.11	1.27%	50.26	0.46%	0.55	0.52	0.00%		795	12.13	0.00
226.8	5.5%	3.11	1.27%	50.21	0.55%	0.55	0.52	0.00%		782	10.30	0.00
225.6	6.0%	3.13	0.63%	50.01	0.95%	0.54	0.52	1.82%		772	8.89	0.30

Table 11 - Switch Mode Power Supply (100Ω) Detailed Results

Switch Mode Power Supply (100Ω)												
Voltage (V)	ΔV(%)	Power (W)	ΔW(%)	Current (mA)	ΔI(%)	$E_{measure}$(Wh)	$E_{calculated}$(Wh)	ΔE(%)	Time	Light Intensity (LUX)	LUX Decrease (%)	CVRf
240.0	0.0%	11.68	0.00%	50.49	0.00%	1.90	1.95	0.00%	Operated for precicelly 10 minutes.	709	0.00	0.00
238.8	0.5%	11.60	0.68%	49.06	2.83%	1.90	1.93	0.00%		739	4.23	0.00
237.6	1.0%	11.52	1.37%	51.00	-1.01%	1.89	1.92	0.53%		770	8.60	0.53
236.4	1.5%	11.48	1.71%	49.39	2.18%	1.89	1.91	0.53%		783	10.44	0.35
235.2	2.0%	11.50	1.54%	48.87	3.21%	1.90	1.92	0.00%		798	12.55	0.00
234.0	2.5%	11.60	0.68%	48.84	3.27%	1.89	1.93	0.53%		804	13.40	0.21
232.8	3.0%	11.55	1.11%	50.41	0.16%	1.88	1.93	1.05%		775	9.31	0.35
231.6	3.5%	11.67	0.09%	50.14	0.69%	1.89	1.95	0.53%		780	10.01	0.15
230.4	4.0%	11.49	1.63%	49.89	1.19%	1.90	1.92	0.00%		794	11.99	0.00
229.2	4.5%	11.66	0.17%	50.17	0.63%	1.90	1.94	0.00%		795	12.13	0.00
228.0	5.0%	11.60	0.68%	50.26	0.46%	1.89	1.93	0.53%		795	12.13	0.11
226.8	5.5%	11.46	1.88%	50.21	0.55%	1.89	1.91	0.53%		782	10.30	0.10
225.6	6.0%	11.60	0.68%	50.01	0.95%	1.90	1.93	0.00%		772	8.89	0.00

Appendix J – Cost Savings

Table 12 - Cost Savings (240V) Detailed Results

Yearly energy cost (based on Synergy Tariff and 240V)													
Device	Assumed Operation Time (Mins)	Power (W)	Units Consumed / day	Weekend		Weekday (October - March)				Weekday (April - September)			
				20.9867c/unit	13.1817c/unit	25.3254c/unit	50.7286c/unit	25.3254c/unit	13.1817c/unit	50.7286c/unit	25.3254c/unit	50.7286c/unit	13.1817c/unit
				7am-9pm	9pm-7am	7am-11am	11am-5pm	5pm-9pm	9pm-7am	7am-11am	11am-5pm	5pm-9pm	9pm-7am
Incandescent Light	720	92.50	1.110	0.370	0.740			0.555	0.555			0.555	0.555
Fluorescent Light	720	21.18	0.254	0.085	0.169			0.127	0.127			0.127	0.127
LED Light	720	9.46	0.114	0.038	0.076			0.057	0.057			0.057	0.057
Electric Toaster	15	907.23	0.227	0.113	0.113	0.113		0.113		0.113		0.113	
Electric kettle	15	2001.28	0.500	0.250	0.250	0.250		0.250		0.250		0.250	
Microwave	30	937.50	0.469	0.234	0.234	0.117		0.234		0.234		0.234	
Refrigerator	-	200.1	2.345	1.173	1.173	0.586	0.586	0.586	0.586	0.586	0.586	0.586	0.586
AC Induction Motor	900	157.77	2.367	1.183	1.183				2.367			2.367	
Switch Mode Power Supply (Loaded)	60	11.68	0.012	0.012				0.012				0.012	
		Total Units / day type		3.458	3.939	1.067	0.586	1.935	3.692	1.184	0.586	4.301	1.325
		Weekend Days	104	359.63	409.64								
		Weekday (Oct-Mar)	134			142.98	78.56	259.25	494.68				
		Weekday (Apr-Sep)	127							150.39	74.45	546.26	168.29
		Cost ($) / day type		75.47	54.00	36.21	39.85	65.66	65.21	76.29	18.86	277.11	22.18
		Total Units / Year	2684.12										
		Total Cost / year	$ 730.84										

Table 13 – Cost Savings (235.2V) Detailed Results

Yearly energy cost (based on Synergy Tariff and 235.2V)													
Device	Assumed Operation Time (Mins)	Power (W)	Units Consumed / day	Weekend		Weekday (October - March)				Weekday (April - September)			
				20.9867c/unit	13.1817c/unit	25.3254c/unit	50.7286c/unit	25.3254c/unit	13.1817c/unit	50.7286c/unit	25.3254c/unit	50.7286c/unit	13.1817c/unit
				7am-9pm	9pm-7am	7am-11am	11am-5pm	5pm-9pm	9pm-7am	7am-11am	11am-5pm	5pm-9pm	9pm-7am
Incandescent Light	720	89.66	1.076	0.359	0.717			0.538	0.538			0.538	0.538
Fluorescent Light	720	20.35	0.244	0.081	0.163			0.122	0.122			0.122	0.122
LED Light	720	9.27	0.111	0.037	0.074			0.056	0.056			0.056	0.056
Electric Toaster	15	860.6	0.215	0.108	0.108	0.108		0.108		0.108		0.108	
Electric kettle	16.821	1915.58	0.537	0.269	0.269	0.269		0.269		0.269		0.269	
Microwave	30	915.20	0.458	0.229	0.229	0.114		0.229		0.229		0.229	
Refrigerator	-	200.1	2.348	1.174	1.174	0.587	0.587	0.587	0.587	0.587	0.587	0.587	0.587
AC Induction Motor	900	157.77	2.367	1.183	1.183				2.367			2.367	
Switch Mode Power Supply (Loaded)	60	11.50	0.012	0.012				0.012				0.012	
		Total Units / day type		3.451	3.917	1.078	0.587	1.919	3.669	1.192	0.587	4.286	1.303
		Weekend Days	104	358.90	407.33								
		Weekday (Oct-Mar)	134			144.40	78.67	257.17	491.69				
		Weekday (Apr-Sep)	127							151.38	74.56	544.29	165.45
		Cost ($) / day type		75.32	53.69	36.57	39.91	65.13	64.81	76.79	18.88	276.11	21.81
		Total Units / Year	2673.84										
		Total Cost / year	$ 729.03										