Australian Power Quality and Reliability Centre

Domestic Energy Saving Devices

Technical Note 13
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1. Executive Summary

This technical note investigates energy saving devices which are marketed for domestic applications. Rapidly increasing energy prices and climate change concerns leading to a desire to reduce energy consumption have seen a proliferation of such devices in the marketplace. Some of the promotional material associated with these devices makes exaggerated, misleading or technically incorrect assertions. This technical note examines the theoretical capabilities of a number of voltage reduction technologies currently in the marketplace. A short review of the way that energy is measured is also included.

2. Introduction

This technical note investigates the technical capabilities of energy saving devices which are marketed for domestic applications and designed to reduce energy costs to customers.

In order to understand how energy saving devices may or may not reduce energy bills it is necessary to have a basic understanding of the way in which electrical loads consume power and how domestic energy usage is calculated. These concepts are discussed in Section 3 of this technical note.

The technical note then examines the theoretical basis for a number of purported energy saving devices. Three prevalent technologies which claim to be capable of reducing domestic energy costs are examined in this technical note. These are devices which reduce the input voltage, devices which correct power factor and devices which mitigate power quality disturbances.

3. Domestic Energy Metering & Tariffs

In order to understand domestic energy usage, it is first necessary to discuss some basic electrical engineering theory. Electrical loads consist of devices which require active (or real) power (P) and/or reactive power (Q) to operate. In the simplest sense, active power does meaningful work while reactive power establishes the magnetic fields which are necessary for equipment to operate. Resistive loads consume active power while inductive and capacitive loads require reactive power to operate. The total current drawn by any load consists of a component of current (I_{ip}) which is in phase with the supply voltage (V) and a component of current (I_{op}) which is out of phase. The in-phase component of the current is associated with active power while the out-of-phase component is associated with reactive power.

The term apparent power (S) is used to describe the combination of active and reactive power required by a load. The relationship between the magnitude of apparent, active and reactive power is given in equation (1) below:

(1) $$S = \sqrt{P^2 + Q^2}$$

The active power (P) consumed by a load is defined as:

(2) $$P = V \times I_{ip}$$

Where V = voltage, I_{ip} = the in-phase component of the current

In NSW, the domestic energy tariff is based on active power consumption. Reactive power consumption is irrelevant. The distinction between power and energy is that energy is a measurement of power usage over time. For active power consumption, the unit of energy is the kilowatt hour (kWh). As such, if a device is to be effective in reducing residential energy costs, it must reduce the number of kWhs consumed.

4. Common Energy Saving Devices

4.1. Voltage Reduction Devices

There are a number of devices which claim to be capable of reducing domestic energy bills which are based on the concept of a reduced supply voltage leading to reduced energy consumption. Reduction in energy consumption by means of reducing the input voltage to appliances exploits the fact that voltage is supplied over a range of levels across distribution networks. This is a necessary characteristic of network design. In Australia, the voltage range is given in AS60038 and is effectively 230 V -11%/-10% or 204.7 V – 253 V. Most appliances found in domestic premises are designed to operate most efficiently at approximately 230 V. As such, if the voltage in a domestic residence is at the upper end of the voltage range, there is scope to reduce the voltage (and potentially reduce energy consumption) with no discernible impact on appliance operation. There are a number of designs available in the marketplace which can reduce the supply voltage including:

- Simple designs which have a fixed step-down transformer (often of toroidal construction).
- Designs with more complicated transformer connection arrangements.
- Designs with voltage sensing circuits which drive static switches selecting taps on multi-tap transformers.
- Power electronic designs which involve switching components which are used to re-construct waveforms. These may also be referred to as voltage regulators.

4.1.1. Conservation Voltage Reduction

Reducing voltage in order to reduce energy consumption forms one part of an energy reduction principle called conservation voltage reduction (CVR). There is significant evidence to suggest that a reduction in voltage level will lead to a reduction in domestic energy consumption. This concept is not new as evidenced by studies such as [1] and [2] from the 1980s.

Recent studies such as [3] and [4] conducted in the USA have shown that reducing voltage levels will reduce energy consumption. For the study presented in [3] a widespread 5% reduction in voltage across an entire distribution network led to a 2% reduction in energy consumption. The study detailed in [4] found the following:

- “CVR provides peak load reduction and annual energy reduction of approximately 0.5% - 4% depending on the specific feeder.”
- “When extrapolated to a national level, it can be seen that a complete deployment of CVR, 100% of distribution feeders, provides a 3.04% reduction in annual energy consumption.”
- “If deployed only on high value distribution feeders, 40% of distribution feeders, the annual energy consumption is still reduced by 2.4%.”

The study presented in [5] was conducted using Australian appliances, voltage levels and distribution network characteristics. The study concluded that a real power reduction of 1.05% and reactive power reduction of 2.28% could be achieved for every 1% reduction in source voltage. The simulation results illustrated that CVR implementations could be effective in Australian networks to reduce demand and energy.

While the studies show the potential of reducing voltage across large distribution networks, they do not ensure that an energy saving will be achieved at a single domestic premises or, if an energy saving can be achieved, they give no indication of the magnitude of this saving. The effectiveness of any CVR implementation will principally be dependent on:

- The existing voltage level at the site due to the fact that the voltage can only be reduced so far before equipment will fail to operate correctly, and
- The appliance mix at the site. Some appliances will use less energy for a reduced input voltage while others may use the same and a small number may use more. In order to understand how voltage reduction can be effective in reducing domestic energy consumption it is necessary to understand the characteristics of domestic appliances. This is discussed in the next section.

4.1.2. Appliance Characteristics

While network studies have shown that reduction in voltage will lead to a reduction in overall energy consumption, for domestic premises, the reduction in energy is heavily dependent on the appliance mix and often comes with other consequences. Some appliances will reduce energy consumption when the input voltage is reduced while a reduction in voltage will have no impact on the energy consumption of others. In most cases, the energy savings claimed by vendors greatly exaggerate the savings that can be made.

As stated above, voltage reduction will only be effective for a subset of appliances. There are three basic appliance behaviour characteristics. These are constant power, constant current and constant impedance. The relationships between power, voltage, current and resistance (the non-reactive component of impedance) are described in equations (3) and (4) below:

(3) $$P = V \times I$$

(4) $$P = \frac{V^2}{R}$$

Where P = Power, V = Voltage, I = Current and R = Resistance.

Constant power loads are just that; they draw a constant level of power regardless of the input voltage. For these loads, any reduction in voltage will lead to a corresponding increase in current. As such, reduction in voltage will not lead to any reduction in the power consumed by these loads. Examples of constant power loads include computers and other electronic devices.

For constant current loads, the current drawn by the device remains the same irrespective of the input voltage. Given the relationship between power, current and voltage shown in equation (3), it is clear that a reduction in voltage will lead to a reduction in power. An example of a constant current load is the compact fluorescent lamp (CFL).

For constant impedance loads, the impedance of the load remains fixed irrespective of input voltage. The relationship between power and resistance shown in equation (4) demonstrates that a reduction in voltage will lead to a reduction in power consumption. Examples of constant impedance loads include heating elements (e.g. kettle, toaster) and incandescent lighting.

Figure 4.1 from [6] shows the impact of reducing the voltage from 122 V to 118 V for appliances used on the American 110 V network.

POWERED-DOWN APPLIANCES		
Appliance	Conserved Power (Watts)	Conserved Power (Percent)
INDUCTION MOTOR		
Fan	4.2	6%
DISPLAY		
CRT TV	2.1	4%
LCD TV	0	0%
Plasma TV	-2	0%
Desktop LCD	-0.6	-2%
LIGHTING		
13-W Compact Fluorescent Lamp (CFL)	0.9	8%
20-W CFL	1	6%
LED (Low Quality)	0.2	6%
75-W Incandescent	3.4	5%
42-W CFL	0.8	2%
LED (High Quality)	0.1	1%
LED (Medium Quality)	-0.1	-1%

Figure 4.1: Effect on Power Consumption when Voltage was reduced from 122 V to 118 V [6]

However, given the fact that energy consumption is measured as power usage over time (as described in Section 3), a reduction in instantaneous power usage is not sufficient to ensure a reduction in energy consumption. Take for example the case of a kettle. For any given amount of water, a certain amount of energy is required to bring the water to boil. Once again, as energy is power over time, for a lesser amount of power, a larger amount of time is required to bring the water to boil. This is illustrated in Figure 4.2 which shows the time and energy required to boil a kettle containing the same amount of water at 220 V and 230 V. It can be seen that at 220 V the kettle takes longer to boil but ultimately uses effectively the same amount of energy. Similar statements may be made regarding all heating elements. For instance, a heater supplied at a lower voltage will consume less energy but will produce less heat, as will stove cook tops. For lights, although they definitely will consume less energy when supplied at a lower voltage, the light output will also be reduced (although this may not be perceptible).

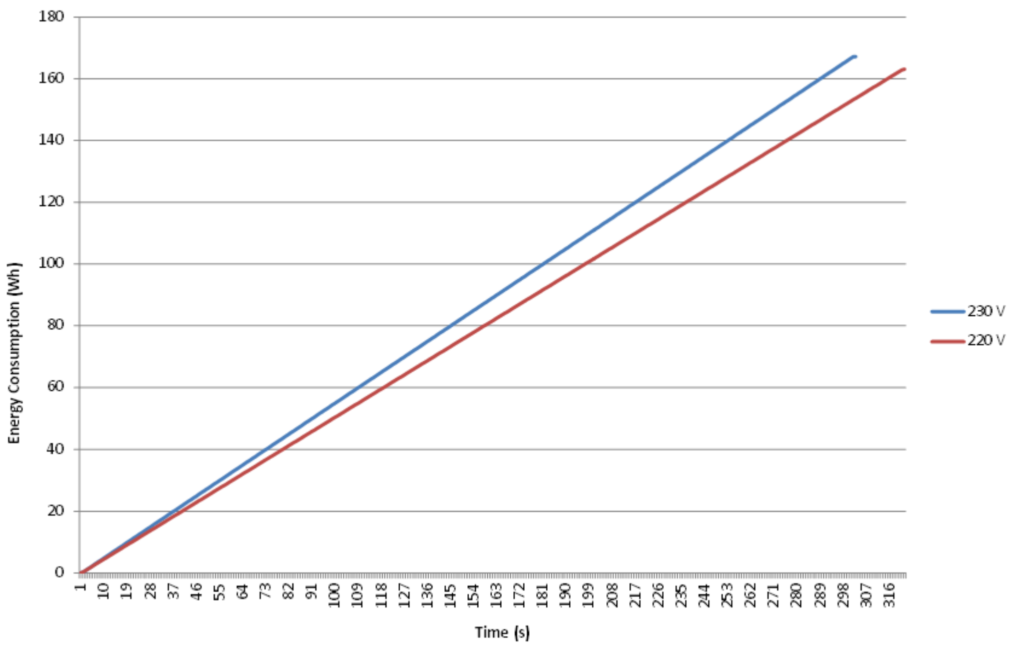


Figure 4.2: Comparison of Energy Required to Boil Water in a Kettle at 220 V and 230 V

The studies detailed in [3] and [6] indicate that the biggest potential for energy saving associated with a reduction in voltage are motors associated with fans, refrigerators and air conditioners. In many cases, these motors are under loaded (or overrated for the load) and are operating at a voltage level other than that where they are most efficient.

4.1.3. Pitfalls of Voltage Reduction

Care must be taken when applying voltage reduction devices as they are not suitable for all locations. If the supply voltage level at a domestic premises is already at the bottom end of the voltage range, application of a voltage reduction device may lead to an undervoltage state. This will result in the possibility of appliances either not operating at all or not operating correctly or efficiently. Another issue for consideration is that voltage reduction devices are typically connected in series with the load. If the device fails, there is a possibility that it may become open circuit leading to a loss of supply.

4.2. Power Factor Correction Devices or Similar

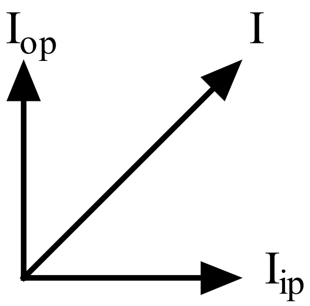
Devices designed for power factor correction reduce line current by supplying the reactive power required by loads locally as opposed to it being supplied by the network. In effect, current opposite to a component of that drawn by the load is supplied to the circuit. In most cases, power factor correction is achieved by connection of shunt capacitors. Many of these devices are no more sophisticated than a number of capacitors in a box. More complex designs include elaborate cases and LED lights to indicate that the device is 'working'. In all cases, the components used in the device would only have a value of tens of dollars or less. Devices of this type make the false assertion that a reduction in line current will result in a reduction in domestic energy bills. In order to prove that a reduction in line current will not lead to a reduction in domestic energy use, it is necessary to describe some basic electrical engineering theory.

Section 3 detailed how domestic energy consumption is calculated and stated that domestic customers are only metered on and charged for the active power (P) that they consume. Based on equation (1) in Section 3 it can be seen that a reduction in Q will lead to a reduction in S. Given that the relationship between S and the current drawn by the load is as described in equation (5), for a fixed voltage, it follows that a reduction in S will lead to a reduction in I.

(5) $$S = V \times I$$

However, a reduction in the total current drawn by the load does not directly lead to a reduction in the active power (the quantity for which domestic customers are billed). To demonstrate why this is so, it is necessary to understand the definition of the quantity P. Based on equation (2) in Section 3, in order to reduce domestic energy costs, it is necessary to reduce the in-phase (I_{ip}) component of the current drawn by the load. Figure 4.3 below shows why power factor correction will not achieve this outcome.

It has been clearly shown on the following page that devices that correct power factor will not save domestic customers money on electricity bills. Added to this, there is another problem associated with these devices. Traditionally, domestic loads were characterised by a lagging power factor, indicating that the load was inductive. However, many modern loads such as consumer electronics have power supply circuits which display unity or even leading power factor characteristics. Under such conditions, application of power factor correction capacitors will not even be effective in reducing line current; indeed if the capacitors are too large, the line current will begin to increase in order to supply the reactive load associated with the capacitors. Adverse harmonic current issues may also occur. Once again, power factor correction will not impact domestic energy consumption costs but may also be undesirable for the electricity network.

<table>
<tr><th>CIRCUIT BEFORE POWER FACTOR CORRECTION</th><th>CIRCUIT AFTER POWER FACTOR CORRECTION</th></tr>
<tr><td>


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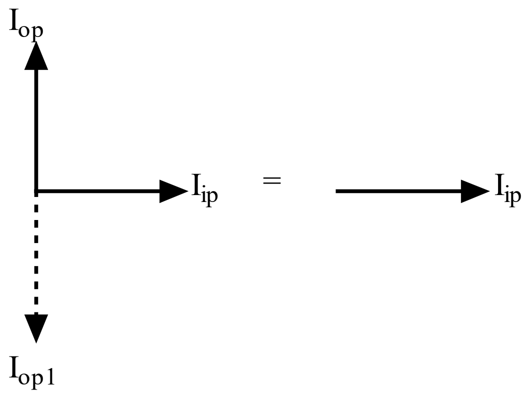

</td></tr>
<tr><td>The total current (I) is the combination of the in-phase (I_{ip}) and out-of-phase (I_{op}) current. The active power (P) consumption for this circuit is given in equation (2).</td><td>Power factor correction basically involves applying a current which is anti-phase to the out-of-phase current (I_{op}) drawn by the load. This is shown as I_{op1} in the diagram above. If exactly the same amount of I_{op1} is applied as the drawn by the load, the out-of-phase current will be completely cancelled resulting in only the in-phase component (I_{ip}) remaining. As such there is a reduction in apparent power (S) and total line current. However, it can clearly be seen that there is no reduction in I_{ip}. Based on the relationship between I_{ip} and P shown in equation (3) there will be no reduction in P and in turn no reduction in kilowatt hour usage.</td></tr>
</table>

Figure 4.3: Effect of Power Factor Correction on Circuits

4.3 Devices which Mitigate Power Quality Disturbances

There are a number of devices on the market which claim to be capable of energy usage reduction by means of mitigation of power quality disturbances such as harmonic distortion and voltage unbalance. These range from special transformer connections such as zig-zag transformers through to devices which claim to be capable of altering 'electron spin'. While in some cases these devices may be capable of power quality disturbance mitigation, in the vast majority of cases the limits placed on power quality disturbances on distribution networks ensure that the energy consumption related to these disturbances is very small. As such, mitigation of these disturbances will have negligible impact on domestic energy consumption and costs.

5. Conclusion

This technical note has examined the theoretical capabilities of a number of energy consumption reduction devices currently available. Overall, there is considerable misinformation in the marketplace regarding the capabilities of these devices and a number of vendors have grossly exaggerated the potential benefits of the devices that they are marketing. This in turn has resulted in exploitation of vulnerable consumers.

The technical note has shown that devices which reduce voltage may be effective in reducing energy consumption. The level of reduction is greatly dependent on the appliance mix within the domestic load. Network wide studies suggest that a reduction of between 0.4% and 1% in energy consumption may be achieved for every 1% reduction in voltage.

There is no theoretical basis upon which devices which correct power factor will reduce domestic energy bills. Devices which mitigate power quality disturbances may theoretically reduce domestic energy costs, however, the limits placed on power quality disturbances on distribution networks ensure that the energy consumption related to these disturbances is very small. As such, the energy cost saving associated with their mitigation will be commensurately small.

6. References

[1] D. Lauria, "Conservation Voltage Reduction (CVR) at Northeast Utilities," IEEE Transactions on Power Delivery, vol. 2, issue 4, pp. 1186-1191, 1987.

[2] B. Scalley, D. Kasten, "The Effects of Distribution Voltage Reduction on Power and Energy Consumption," IEEE Transactions on Education, vol. 24, issue 3, pp. 210-216, 1981.

[3] The CSU, Chico Research Foundation, Willard H. Wattenburg, "Advanced Switches for Soft Blackouts, Critical Infrastructure Protection, Unanticipated Discovery of Emergency Voltage Reduction for Grid Protection - PIER Final Project Report," Report prepared for California Energy Commission Public Interest Energy Research Program, 2006.

[4] Pacific Northwest National Laboratory, "Evaluation of Conservation Voltage Reduction (CVR) on a National Level," Report prepared for US Department of Energy, 2010.

[5] A. Pisani, "The Validity of Conservation Voltage Reduction in Australian Distribution Networks to Reduce Both Consumer and Network Costs", Undergraduate Thesis, University of Wollongong, 2011.

[6] Peter Fairley, "An Easy Smart-Grid Upgrade Saves Power," in IEEE Spectrum, vol. October 2010: IEEE, 2010.

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