2015

Principles of Economic and Energy Efficient Cable Sizing

Background Material for ECS Example in AS3008

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[Industry Report]

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Contents

1 BACKGROUND

In Australia, electrical cable sizing practice is guided by AS/NZS 3000 and AS/NZS 3008. These two standards are based on safety. In an atmosphere of increased energy costs and environmental concern it is quite justifiable in many situations to augment the initial safety based cable selection with one based upon economic and environmental considerations. Economic cable sizing (ECS) describes a two-step process: firstly it establishes a minimum allowable cable size that meets all safety requirements and then it selects a cable that is both of a size equal to or greater than the minimum allowable size and the most economical over its lifetime. The two components used to establish the most economic cable are its initial costs (the cost of cable and its installation) and the lifetime cost of energy lost in the cable due to its resistance (henceforth I^2R losses). This process is descried in more detail below.

2 PRINCIPLES OF ECONOMIC CABLE SIZING CABLES

The principles and practice of sizing cables on economic principles is not new. The IEC 60287-3-2[1] document has been in circulation for over 10 years. It describes a theoretically equivalent process to that described here but it requires greater technical and economic knowledge and understanding to be effectively applied. The ECS principle is routinely applied to situations of scale sufficient to warrant detailed analysis. However, it is likely that the cable sizing of most domestic and a significant number of commercial buildings are based entirely upon safety rather than economic and environmental considerations. This situation results in many consumers paying more for electricity than they should.

The background for economic cable sizing is provided in the general part of IEC 60287-3-2. The key points of economic cable sizing are as follows.

The common use of a cable sizing standard is to select a cable size of minimum admissible cross-sectional area that is safe to use. Because cable size and cost are directly related, the selection of a minimum cable size also minimizes the initial investment cost of the cable. However, it does not take into account the cost of the losses that will occur during the life of the cable. The cost of losses is increasing due to increased energy costs and increasing cable insulation ratings that enable cable to operate at higher temperatures. To provide a safe and economic cable, the sum of the initial cost and the cost of the losses over the economic life of the cable should also be minimised. For a significant number of situations a larger size of conductor than would be chosen based on minimum initial cost will lead to a lower power loss for the same current and will, when considered over its economic life, be much less expensive. For a typical example given in IEC 60287-3-2 the saving in the combined cost of purchase and operation is of the order of 50 %.

The future costs of energy losses during the economic life of the cable are calculated by making suitable estimates of load growth and cost of energy. The most economical size of conductor is achieved when the sum of the future costs of energy losses and the initial cost of purchase and installation are minimised. Initial and ongoing costs are expressed in comparable economic values. The present value of the installation is combined with the equivalent present value of the ongoing costs which is the discounted cost of the future energy losses. The impact of inflation is omitted on the grounds that it will similarly affect both the cost of borrowing money and the cost of energy. Calculation of the present value of the costs of the losses requires appropriate values for the future load, energy price and the discount rate over the economic life of the cable. It is assumed that the financial parameters remain unchanged during the economic life of the cable.

Possible savings are not critically dependent on the conductor size when it is in the region of the economic value. This has two implications: a) the impact of errors in financial data, is small and considerable savings can be achieved using data based on reasonable estimates; and b) other considerations taken to choose a conductor such as fault currents, voltage drop and size rationalisation, can all be given appropriate emphasis without losing the significant benefits of choice by economic size.

2.1 SELECTING A CABLE

There are three cable selection scenarios:

1. Minimum cable selection that is based on safety and sized according to AS/NZS3000. For maximum demands below 100A there is usually a conservative approach that leads to sizing that is greater than

[1] **IEC 60287-3-2 Electric cables – Calculation of the current rating – Part 3-2: Sections on operating conditions – Economic optimization of power cable size.**

the minimal permissible. Additionally, for domestic and small commercial installations it is common for the contractor to use rule-of-thumb solutions rather than calculations;

2. Engineered solutions that are based upon AS/NZS3008. To achieve “industry best practice solutions” the contractor or consultant reduces initial cable costs but retains spare capacity for all high current applications; and
3. Economic cable selection that is based upon energy and environmental considerations. If a cable upsize is economically feasible, there will be a larger initial cost that is met, in an acceptable period, by savings due to lower operating costs that are due to savings from reduced I^2R losses.

For the commercial building exercise considered in section 2, 1 can be ignored and the comparison is made between 2 (BAU) and 3. Thus, AS/NZS3008 forms the BAU case from which the benefits of economic sizing are measured. The cable size is at least the smallest cable that satisfies the following three requirements:

- Current-carrying capacity (maximum demand and cable size);
- Voltage drop; and
- Short-circuit temperature limit.

Cables sized according to this process formed the BAU[2] case in the following analysis. Such cable sizing may be augmented due to a more holistic approach to the installation – in such cases it is typical to upsize from the minimum allowed by the Standards. Such practices are difficult to quantify and in this report the BAU is based on what is considered current industry best practice.

2.2 ECS FOR RESIDENTIAL BUILDINGS

Whilst this document concentrates on the benefits of ECS for the commercial sector, ECS is important to the residential sector which is responsible for about 28% of electricity consumption and over one half of the markets value. ECS for residential installations are covered in the document “Principles and Benefits of Economic and Energy Efficient Cable Sizing - Residential - AusEng April 2013-V1”.

Important points to note in ECS for a residential installation are:

The market is changing. The market is currently in transition between a rather stationary supply and demand market to a rapidly changing one. Some items that contribute to this change are:

- Technology: LED lighting, brushless d.c. motors, rooftop solar PV, rooftop solar water heating and plugin electric vehicles.
- Electricity pricing: Electricity in Australia is moving to a three component charging system of energy cost, capacity charging and a service charge. Elasticity’s of demand impact on the price of energy and hence the value of the energy saved. For example, pricing may have a significant impact on electric loads such as a swimming pool pump but no effect on the time of cooking for a working family.
- Time electricity is used.

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[2] Standard industry practice is assumed to be according to the prevailing Standards as they presently represent the best business case for installers.

3 ECS FOR COMMERCIAL BUILDINGS

This section explores the core and broader concepts when ECS is applied to commercial buildings. This section is based upon the document Principles and Benefits of Economic and Energy Efficient Cable Sizing - Commercial - AusEng April 2013 V1.

3.1 KEY FINDINGS

For commercial buildings there are potential economic and environmental benefits to augmenting the normal sizing of electrical cables that are determined by the application of AS/NZS3000 and AS/NZS3008 with economic sizing. Both key benefits accrue from reduced electricity losses in the cables. The background to the impact of utilisation is given in section 2.2. More detailed data is required to quantify the costs and benefits satisfactorily and the results given in this report must be taken in the context of concept/process development rather than outcomes from a well informed and mature process.

The results[3] presented in this section indicate that, in the absence of a carbon price[4], for commercial installations economically selected cables would:

- Save about 0.53% (reduction of supply losses from 0.92% to 0.39%) of electrical energy used in commercial buildings. The full impact of this would be equivalent to removing about 68MW of generation capacity and 34MW of generated electricity which is more than the impact of MEPS2 for transformers;
- Have acceptable payback periods in comparison to the asset lifetime with an average B/C ratio of 7; and
- Achieve greenhouse gas abatement of about 0.3MTpa at a negative cost up to - $83/T.

While, for most cases the cost savings accruing from economical cable sizing would service the extra capital required, the split benefits market failure would need to be overcome.

IMPORTANT NOTES

- These examples are for current industry best practice.
- Not all cases are positive, for one case increased cable sizes are not available and for one case it was uneconomical to increase the cable size.
- The results are based on one installation, the knowledge of the overall market is incomplete and assumptions have been made to provide indicative trends for the national market.
- Market failures such as split incentives will always exist and it is through instruments such as industry codes of practices, standards and building codes that these will be mitigated.

3.2 ACKNOWLEDGEMENTS

For the commercial section, the BAU cable selections based on AS/NZS3008.1.1 were made using core data and software that was kindly provided by Roger Sharp. Roger also made many suggestions to improve the original draft. The authors also acknowledge the contributions of Watson Li of Prysmian.

[3] These results are very sensitive to the load utility and the cost of electricity which does not include a carbon price. Therefore the results are conservative estimates.

[4] A carbon price would add substantially to the benefits but the exact impact of a carbon price is uncertain it has not been included in the analysis.

3.3 BACKGROUND

Commercial buildings are classified as Class 3 and 5 to 9 buildings (see appendices 1 and 2). They include office buildings, shops, restaurants, car parks, industrial buildings and hospitals. It has been estimated that about two-thirds of national employment and economic activity takes place in commercial buildings[5] and large amounts of electrical energy are required to support this. The Commercial sector energy use is about 56,320GWh/y (22% of all electricity use in Australia pa) and is growing by about 2.3%[6]. In Australia, Commercial buildings are responsible for approximately 10% of Australia's greenhouse gas emissions and those emissions have grown by 87 per cent between 1990 and 2006[7]. The total number of commercial buildings in Australia is about 4,000[8].

In addition to improving the direct savings due to reducing cable losses there may be other benefits. For example, during the "Power Cable Rating Calculations" course in Sydney recently, course leader Dr. George J. Anders[9] mentioned an experience he had with a concrete floor, where the heat produced by the electric cables buried in the concrete was too hot to walk on with bare feet. The reduction of cable heat losses (19kW in the example used in this report) in air conditioned spaces will add to the economic benefits but are not accounted for here.

A quick web search found the Department of Standards Malaysia reference to the standard MS IEC 60287-3-2: 2003. Their website[10] indicates "This Malaysian Standard is identical with IEC 60287-3-2:1995 and its Amendment 1:1996. This Malaysian Standard deals solely with the economic choice of conductor size based on joule losses. Voltage dependent losses have not been considered[11]."

The application of economic cable sizing in China indicates that substantial energy cost savings were realised when electrical cables to industrial sites were sized according to optimised lifetime benefits. It was reports of the Chinese experience that prompted a previous analysis of economic cable sizing for residential buildings by AusEng[12]. This initial work indicated that there were significant benefits due to economic sizing when compared to using AS/NZS 3000 and AS/NZS 3008 that are based on safety. This approach involved replicating the decision making process for selecting safe cables and augmenting this with an economic assessment that selected a cable of greater cross sectional area based on the optimal NPV of initial costs and cost savings due to reduced losses over a 20 year period.

In response to the above information, the ICAA commenced a research project to quantify the benefits of economic cable sizing for Australian residential and commercial buildings. This report describes the analysis and results for commercial buildings.

[5] Consultation regulation impact statement, - Proposal to Revise the Energy Efficiency Requirements in the Building Code of Australia for Commercial Buildings – Classes 3 and 5 to 9. ABCB Sep 2009.
[6] Consultation regulation impact statement, - Proposal to Revise the Energy Efficiency Requirements in the Building Code of Australia for Commercial Buildings – Classes 3 and 5 to 9. ABCB Sep 2009.
[7] Source: http://www.climatechange.gov.au/what-you-need-to-know/buildings/commercial.aspx)
[8] Property Council of Australia, http://www.propertyoz.com.au/
[9] With Kinectrics (formerly Principal Scientist in the Electric Systems Technology Unit of Ontario Hydro Technologies)
[10] http://www.sirim.my/techinfo/catalogueonline/Subject/29.html
[11] Capacitive losses.
[12] The core approach is based on material and advice supplied by Roger Sharp

3.4 ASSUMPTIONS

The key simplifying assumptions were:

- The commercial price of electricity is constant over the modelling period (20c/kWh)[13];
- The discount rate is 7%;
- The asset lifetime is 50 years but 20 years is used to estimate the NPV[14];
- The costs of the cable are one off and upfront;
- There is no difference in costs between installing different size cables;
- The maximum allowable voltage drop is 5% or 2.5%; and
- The cable upsizing is one size; in reality the economically optimal size is often more than a one size upgrade. See note below.
- Conductors are protected by appropriately coordinated circuit protection that is matched to the cable properties, maximum demand, voltage drop, thermal environment and other items considered by AS3008.

NOTE: **Table** 1 shows the case for a cable that would be normally sized at 16mm^2, is justified at 25mm^2 but would be optimally sized at 35mm^2.

Table 1: **Optimal total NPV for MCCE-GF-1 circuit indicating that increasing the cable size from 16mm^2 to 35 mm^2 leads to optimal cable sizing.**

Active area (mm^2)	Total NPV ($)	Payback period (y)	Comment
16	-	-	BAU from just applying the appropriate standards
25	352.5	6.0	For upgrading one cable size only
35	**583.8**	**5.0**	**The optimal value**
50	-37.4	21.4	No economic case for this cable size

Source: AusEng 2015.

[13] The pricing of electricity varies with time and periods of high electricity use correspond to high costs (**Figure 26**). As this is a concept paper that describes the key principles of economic cable sizing and how it may be applied several key simplifications have been made including a fixed price – see appendix.

[14] Based on an estimate of refit periods.

3.5 UTILISATION

In a perfect world all circuits would be uniformly and fully loaded but real circuits have:

- Intermittent loading – e.g. mechanical load may be high (chillers) or very low (fire pump);
- Voltage drops; and
- Spare capacity.

Utilisation tries to capture how the cable is used, it has two dimensions:

- Time. A load can be on 100% of the time, off all the time or somewhere in between these two limits; and
- Current. A load current can be on 100% of the maximum demand, off all the time or somewhere in between these two limits.

Some high-load appliances are used for very short times. Some low loads such as lighting use very little current and have low energy needs. However, there are many loads that fall somewhere in between
To account for underutilised cables and intermittent use, the lost energy is the average loss per time period. On this basis the annual lost energy is calculated according to equation 1.

$$\text{Energy} = \frac{\sum_{d=0}^{365\,days}\left[\frac{\sum_{h=0}^{24hr}(I_{MD} * U_I)^2\,\mathrm{R}\times \mathrm{U}_t}{24}\right]}{365} \qquad \text{Equation 1}$$

Where:

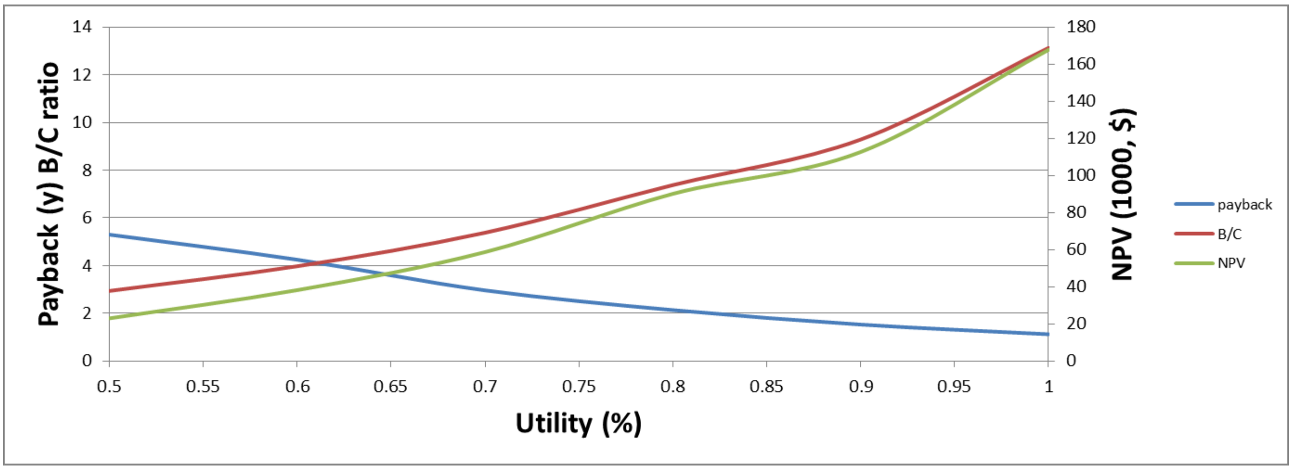
I_{MD} is the maximum demand,
U_i is the current Utility and is the percentage of the maximum demand ($0<U_i<1$), and
U_t is the percentage of time the load is on during each hour.

The case to increase the cable size improves as the utilisation increases. Some devices such as hot water ring mains motors may run all the time, solar panels will probably be utilised no more than 50%, others such as sprinkler pumps might be utilised much less. It is expected, but not yet verified, that cables used in commercial or high density dwelling installations will in general be more heavily utilised that those in single dwelling installations.

Appendix D shows data that includes load factors for South Australia (about 50%). Whilst the use of such averages for overall network use is limited when applied to very specific loads they provide a plausible calibration of utilisation estimates. It is also to be expected that in the near term load curves will change due to many factors including pricing changes and direct load control (AS4755). This should cause loads to flatten out, and as they do, one dimension of the utilisation, the time of use, will become less significant for many cables.

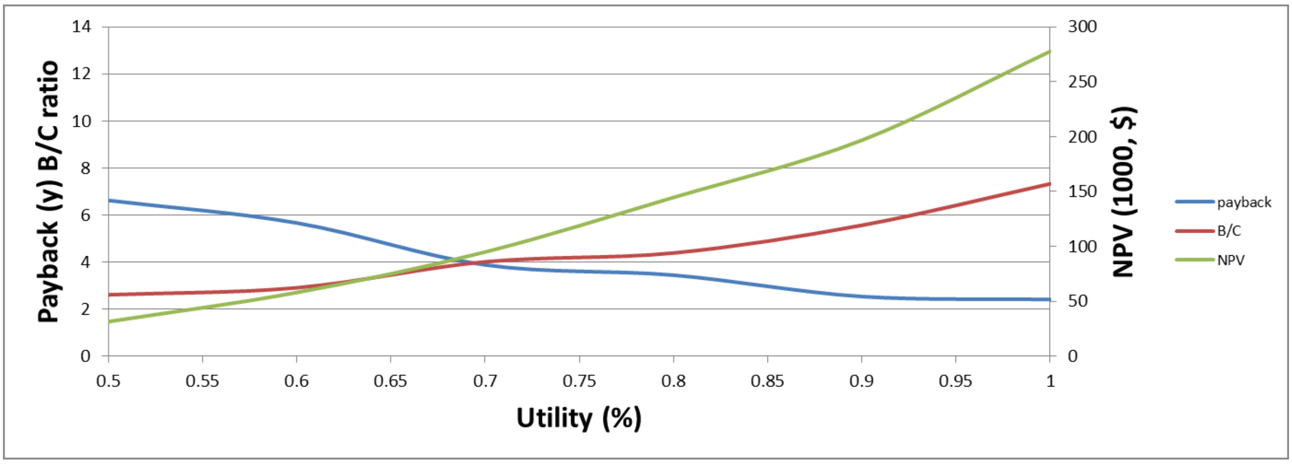
It is therefore important to get a sense of how the benefits depend on the utility. **Figure 1** shows the impact of changing the utility (where only the current was varied to change the utility). Each payback period, NPV and B/C value in this figure are averages for that utility of all the for cables in example 1 (**Table 4**). Even though technically any B/C ration above unity is sufficient to justify and upsize, for a utility below 50% the benefits are not in likely practice sufficient to warrant a cable upsizing. For utilities from 50% to 100% the payback periods are acceptable. **Figure 2** shows the case when optimal ECS is performed.

Figure 1: Single–upgrade: Average Payback period, B/C ratio and NPV for all cables considered and a function of cable utility where U_t=1 and U_i is the percentage of the maximum demand.



Source: AusEng analysis 2015.

Figure 2: Optimal ECS: Average Payback period, B/C ratio and NPV for all cables considered and a function of cable utility where U_t=1 and U_i is the percentage of the maximum demand.



Source: AusEng analysis 2015.

3.5.1 Impact on energy loss

The energy saved is expressed by the following equation:

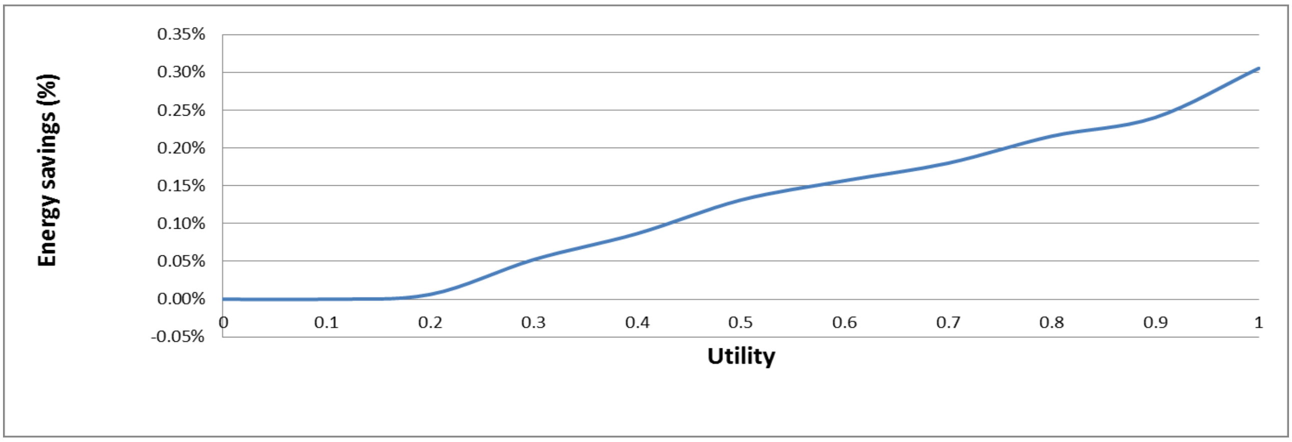
$$\text{Energy Savings} = \frac{\sum_{cable\ 1}^{cable\ n} I_{norm}^2 R_{norm}/P_{load}}{n} - \frac{\sum_{cable\ 1}^{cable\ n} I_{ECS}^2 R_{ECS}/P_{load}}{n} \qquad \text{Equation 2}$$

Where,

ECS = values for ECS derived cable,
n = the number of cables,
Norm = values for normal AS/NZS3008 determined cable, and
P is the power delivered to the load (W).

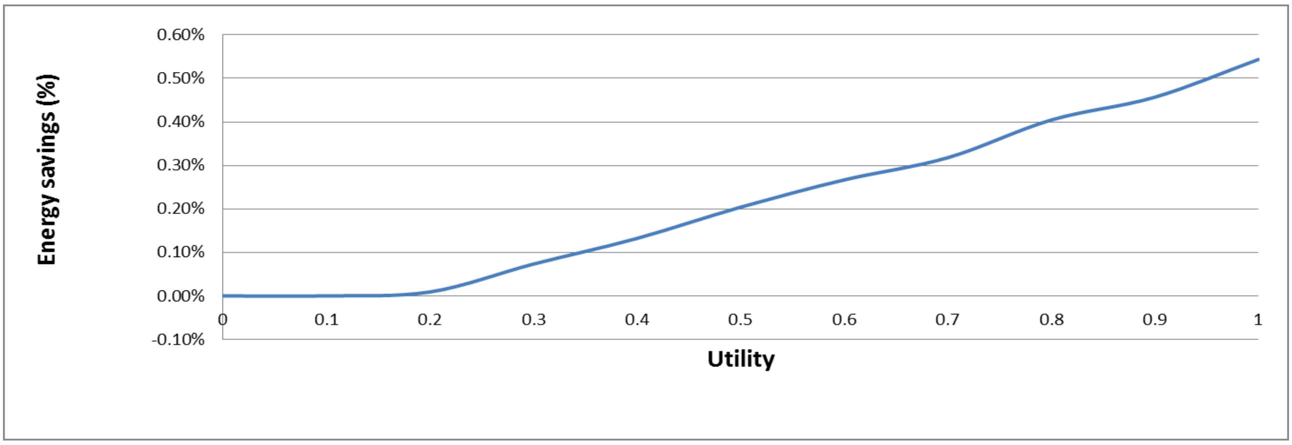
Figure 3 illustrates how the energy savings depend on the utilisation – the savings peak at about 0.5%. The average value for the example installation is about 0.31%. This was a randomly selected modern example and quite possibly represents typical installations. Moreover, the 0.31% savings corresponds to an utilisation of about 60% which is comparable to the earlier 50% figure derived from network average utilisation. Obviously, this is a key 'uncertainty' and in future, its 'sensitivity' needs to be analysed more closely, which could mean a broad range of evaluated benefits (50% to 80%) than that given in this report. If this were so, and if ECS were widely adopted, then ECS has the potential to save up to 0.31% of electrical energy in commercial buildings.

Figure 3: Single size ECS upgrade: Energy savings.



Source: AusEng analysis 2015.

Figure 4: Optimal ECS: Energy savings.



Source: AusEng analysis 2015.

3.6 COSTS AND BENEFITS

The costs modelled are the marginal costs in moving from the normally selected cable to the economically selected cable, with the assumption that installation costs do not change with cable size. Benefits depend on many factors including the cable environment, the utilisation of the cable and the cost of electricity. Economic benefits will substantially increase as electricity costs rise, as would be the case if carbon pricing were introduced.

3.6.1 Summary

Table 2 summarises the key economic and environmental characteristics of the cable optimisation for 100% utility.

Table 2: Summary of economic and environmental characteristics for 100% utilisation.

ITEM	UNITS	Single size ECS upgrade	Reference	Optimal ECS upgrade	Reference
NPV	$ (1000)	166	NPV Figure **5**	273	Figure 6
B/C		11.9	Figure 7	7.3	Figure 8
Payback Period	Years	1.1	Figure 9	2.4	Figure 10
CO_2-e reduction	kTpa	172	Figure 19	306	Figure 20
Abatement cost	$/T	-90	Figure 21	-82.9	Figure 23

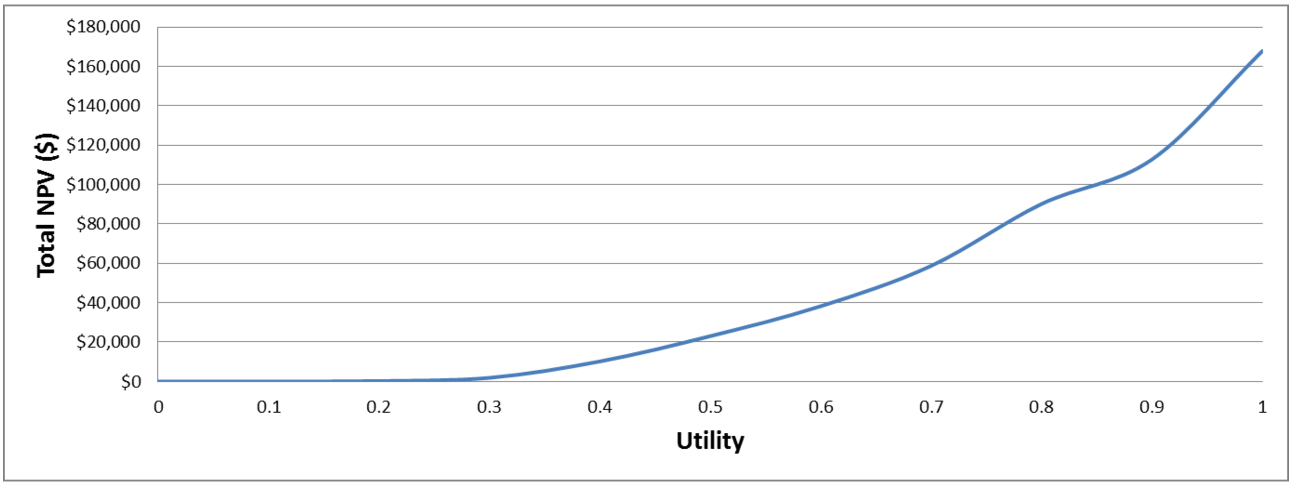
Source: AusEng 2015.

The remaining subsections illustrate how the NPV, B/C ration and Payback period depend on the utility. The NPV for the most economic cable will always exceed that of the single size upgrade except when the ECS is the single size upgrade or there is no ECS. However, the B/C ratio and the payback period will appear better for the single size upgrade because the marginal benefits decrease as a larger cable size is selected.

The environmental results are explained in section 3.13.

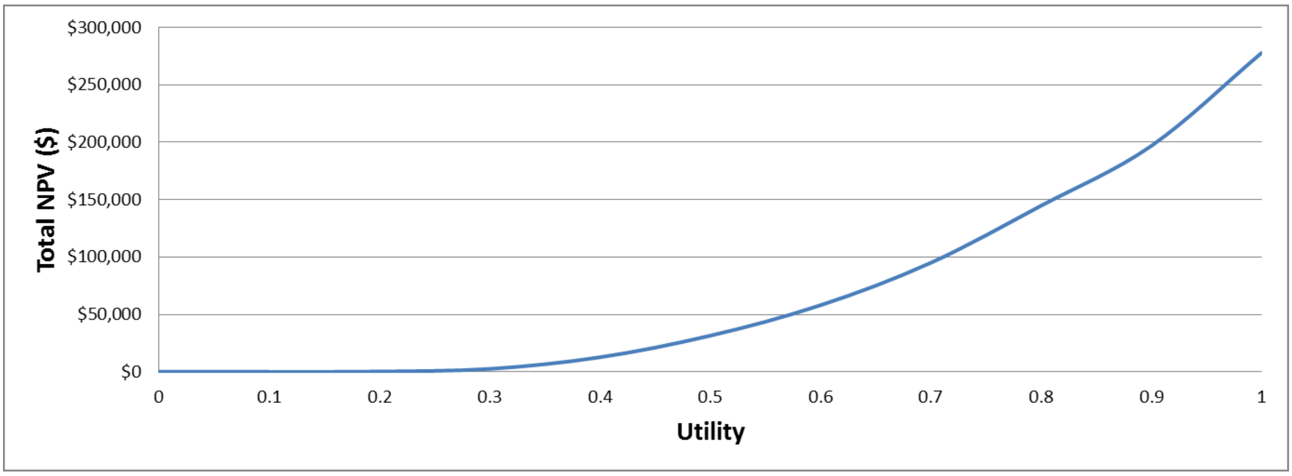
3.6.2 NPV

Figure 5: Single size ECS upgrade: Total NPV.



Source: AusEng analysis 2015.

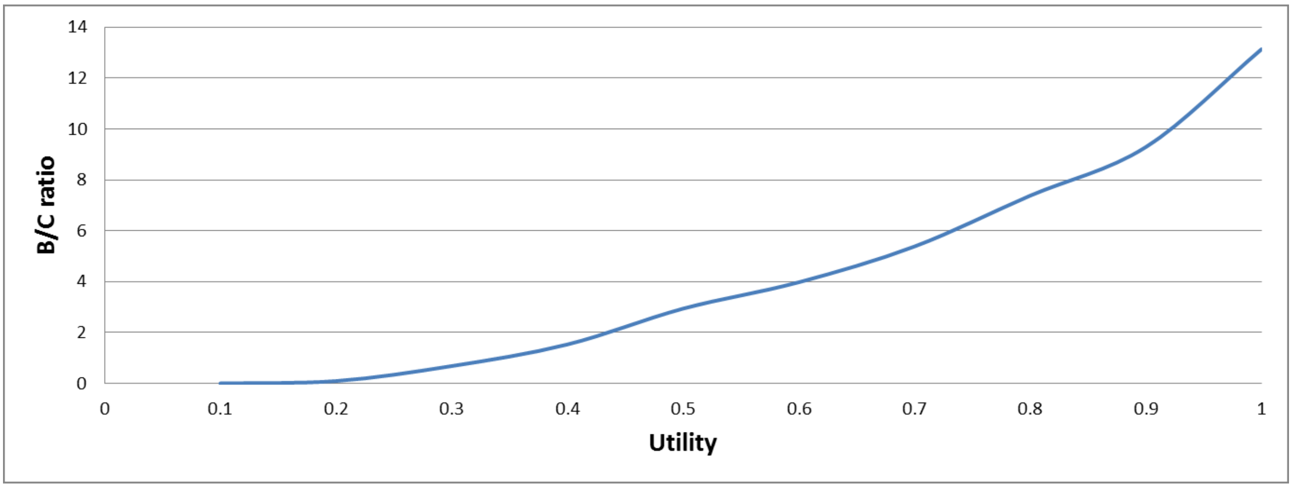
Figure 6: Optimal ECS: Total NPV.



Source: AusEng analysis 2015.

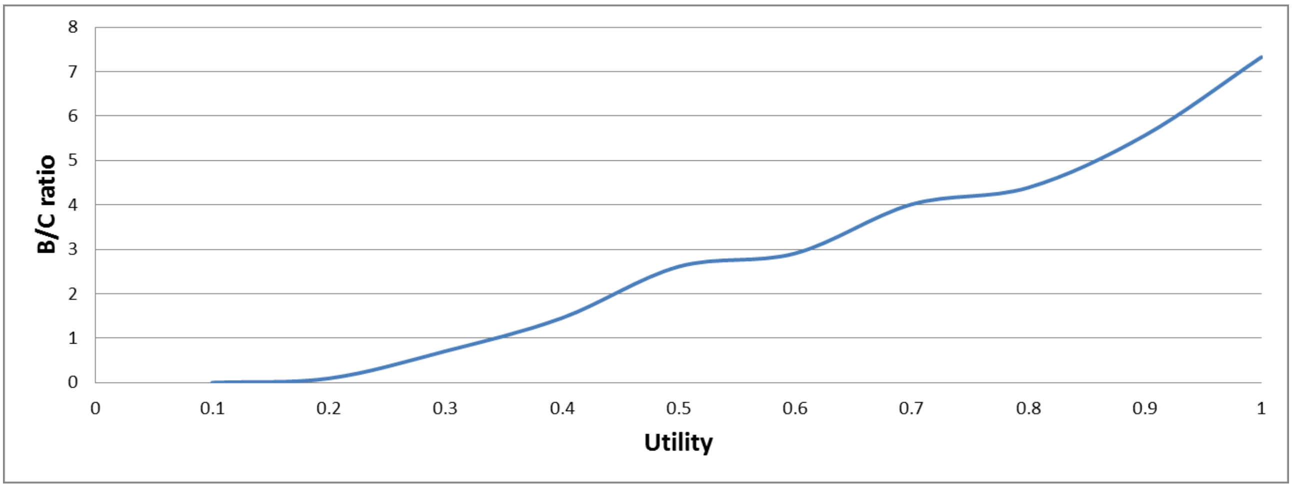
3.6.3 Benefit to cost

Figure 7: Single size ECS upgrade: Dependence of the average benefit cost ratios on cable utility for the situation given in the example.



Source: AusEng analysis 2015.

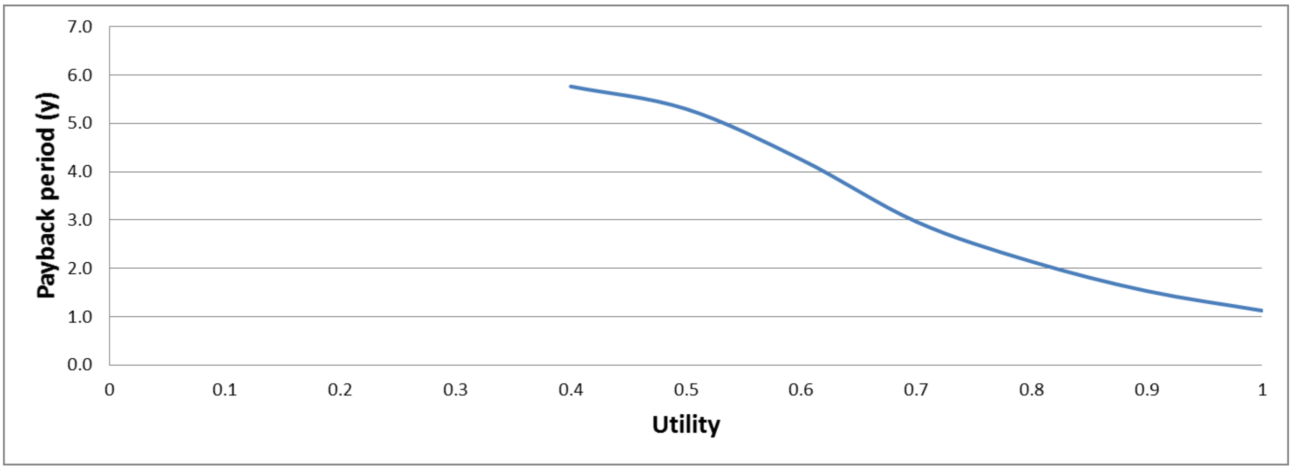
Figure 8: Optimal ECS: Dependence of the average benefit cost ratios on cable utility for the situation given in the example.



Source: AusEng analysis 2015.

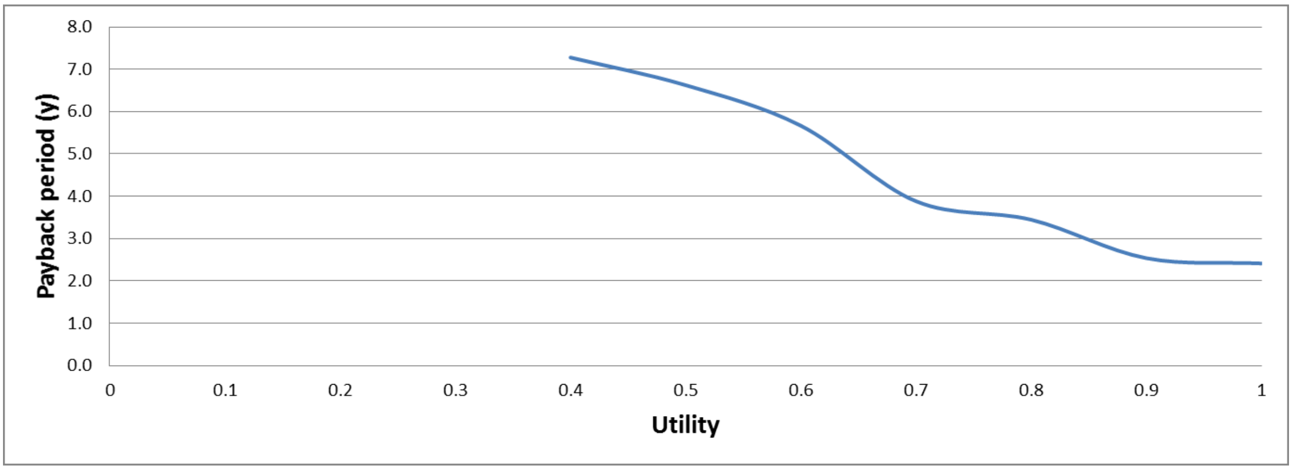
3.6.4 Payback period

Figure 9: Single size ECS upgrade: Dependence of the average payback period on cable utility as given in the example. For a utility under 40% the payback period becomes greater than 10 years for the example.



Source: AusEng analysis 2015.

Figure 10: Optimal ECS: Dependence of the average payback period on cable utility as given in the example. For a utility under 40% the payback period becomes greater than 10 years for the example.



Source: AusEng analysis 2015.

3.7 TEMPERATURE

Cable temperature depends on many factors including its environment, size and current. As a cable's temperature increases so does its resistance and losses due to I^2R. Reduced losses due to a colder cable mean savings for the entity paying for the electricity supplied by the cable – but this is only one dimension of temperature related costs. The pivotal role temperature plays in electrical installations is illustrated in the simplified model of **Figure 11**.

In general, degradation may result from running an asset close to or above its rating for long periods or it may accelerate during short term events that may occur in emergencies that can cause significant electro-mechanical stress as well as temperature related degradation. The lifetimes of cable and transformer insulation and oils are well known to be temperature dependent. Raised temperature reduces asset lifetime and reduced lifetime comes at a cost. Insulation degradation is a strong function of temperature and if copper conductors are held above 120C^o for long periods of time it may become annealed and lose their short circuit current rating. Mairs observes that designs that maximise fault containment may inadvertently lead to higher temperatures and therefore losses. Additionally, he emphasizes that excessive temperatures reduce both lifetimes and performance. Mairs observes that the advantages of some enclosure designs that enhance fault containment may be offset by the disadvantages. Cable, transformer or switchgear temperature may not be due to the individual elements own heat but the combination of all heat sources. This point was made by Mairs when he considered temperature dependent losses of conductors in an enclosure.

The following list is from Mairs[15] indicates how some assets are affected by temperature:

- Shorten lifetime of all components (insulation lifetime reduction and for insulation oil accelerated thermal-oxidative ageing) – see note;
- Annealed copper – reduce short circuit current rating;
- Reduce integrity of joints;
- Increase losses; and
- Increase costs of losses.

Note: A measure of thermal degradation of the insulation present in the transformer is the degree of polymerization of the insulation which proceeds at a temperature dependent rate that may double for every 10C^o increase from room temperature (Arrhenius' equation). For transformers a recent work[16] that shows that keeping hotspots reduced by 22C^0 can add 5% to the transformer's lifetime.

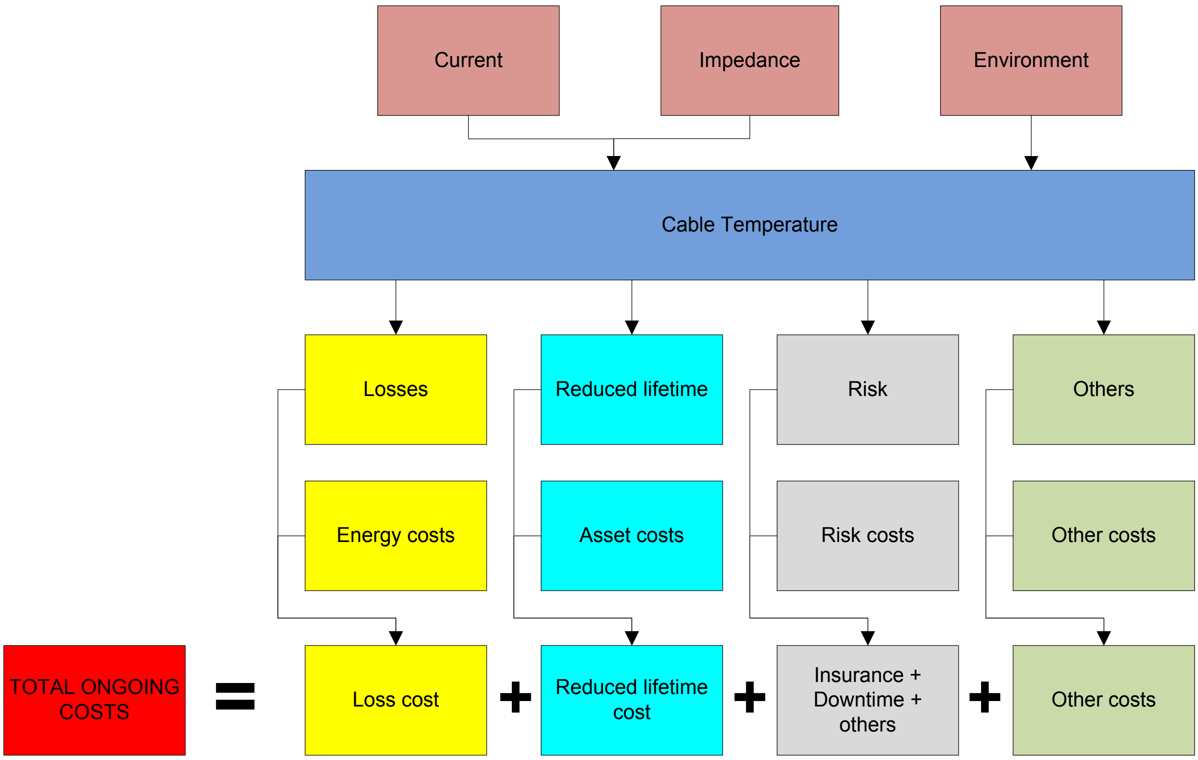
Additional benefits that have not been factored into the present calculations include:

- Reduced air-conditioning requirements when cable is in air-conditioned space. For example if the 1500kVA supply example in this report were in an air conditioned space supply it would create 10kW of additional heat loading; and
- Increased safety and lifetime of expensive and critical temperature sensitive elements including cables (lifetime), busbars, transformers, switch gear and metering equipment.

Thus, the benefits of reduced conductor temperature accrue from more than just savings due to reduced I^2R losses.

[15] William (Bill) Mairs (Fault Containment or Fault Creation, W.F Mairs, Engineering Manager, Nilsen Electrical Industries Pty Ltd, AEEMA Symposium April in 1982)
[16] A study of life time management of Power Transformers at E.ON's Öresundsverket, Malmö. Chaitanya Upadhyay, June 2011.

Figure 11: Simple model of on-going costs in an electrical installation.



Source: AusEng analysis 2015.

3.7.1 Cables

The normal selection of a conductor requires an estimation of the cable temperature and then the corresponding cable impedance and finally selecting a suitable cable size from appropriate tables in the standard. In current practice, the conductor temperature at a given current is estimated using equation 4.4(1) of AS3008:

$$T_O = \left(\frac{I_0}{I_R}\right)^2 * (T_R - T_A) + T_A \qquad \textbf{Equation 3}$$

Where,

I_0 = operating current, in amperes,
I_R = rated current given in Tables 4 to 25, in amperes,
T_0 = operating temperature of cable when carrying I_0,
T_R = rated or maximum operating temperature determined from Table 1 when carrying I_R, and
T_A = ambient air or soil temperature = under rated conditions = 40°C for air and 25°C for ground.

Hence for a 400mm^2 cable rated at 110C^o for 2730A, limited to a maximum demand of 2100A and located in air the rated maximum operating temperature is:

$$T_R = \left(\frac{2100}{2730}\right)^2 * (110 - 40) + 40 = 81\ C^o \qquad \textbf{Equation 4}$$

Once the predicted cable temperature is determined, the temperature used for further calculations is selected from the next highest discrete value that is used in AS3008 (for example the data in table 35 of AS3008 is arranged in columns according to temperature) – the choices are 45°C, 60°C, 75°C, 80°C, 90°C or 110°C. For this example the next discrete value greater than 81°C is 90°C.

For certain calculations the exact dc resistance is required and this can be determined from a linearized form of the dependence of resistance on temperature given by Mairs which is consistent with NIST data as given in Equation 5.

$$T_2 = \frac{R_2}{R_1}(235 + T_1) - 235 \qquad \text{Equation 5}$$

Where,

T_1 = temperature when conductor resistance is R_1, and
T_2 = operating temperature of cable when conductor resistance is R_2.

This approximation can be rearranged to give the resistance at T_2.

$$R_2 = R_1\left(\frac{235 + T_2}{235 + T_o}\right) \qquad \text{Equation 6}$$

Cables can be assumed to be long thin solid cylinders of conductor with or without an insulating layer and for most practical purposes their thermal and electrical properties are relatively easy to model and their characteristics tabulated for a variety of environmental conditions. Although this should be qualified by acknowledging that there are many ways to rate cables[17]. Table 3 shows the expected dependence of the losses on the current using characteristic for the tables in AS3008. The purple coloured entries in this table indicate that if the current is one half the maximum value the cable rating then the losses are about one quarter the maximum allowable value. Economically this means that greater benefits are achieved when the current is reduced from the rated value.

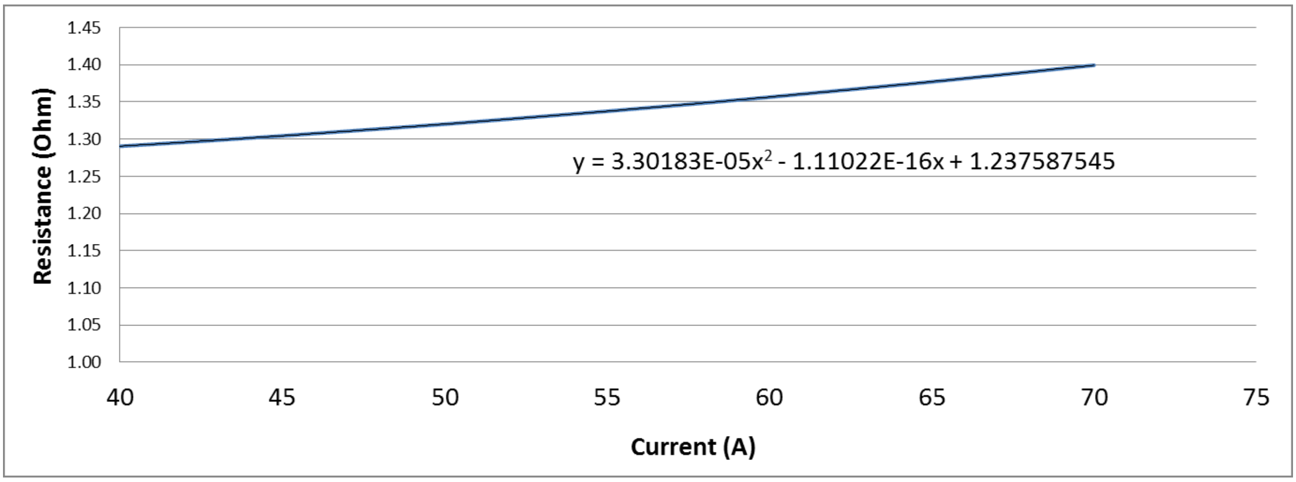
Table 3: Calculations for a single core 16mm^2 thermoplastic rated cable based in the a.c resistance at 50Hz of Cu Single Core Cables.

Current	**Temperature**	**Resistance**	**Power Loss**	**% max**
(A)	(C)	(Ohm)	(W)	
0	40.00	1.24	0	0.0%
5	40.18	1.24	31	0.5%
10	40.71	1.24	124	1.8%
15	41.61	1.25	280	4.1%
20	42.86	1.25	500	7.3%
25	44.46	1.26	786	11.5%
30	46.43	1.27	1141	16.6%
35	**48.75**	**1.28**	**1566**	**22.8%**
40	51.43	1.29	2065	30.1%
45	54.46	1.30	2642	38.5%
50	57.86	1.32	3300	48.1%
55	61.61	1.34	4046	59.0%
60	65.71	1.36	4883	71.2%
65	70.18	1.38	5818	84.9%
70	75.00	1.40	6857	100.0%

Source: AusEng 2015.

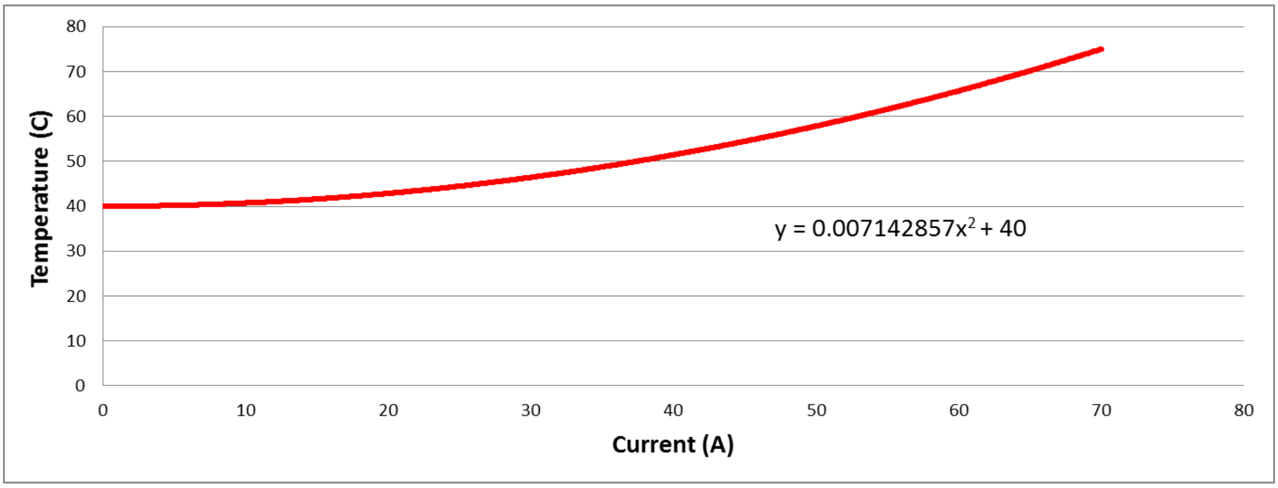
[17] Review of Power Cable Standard Rating Methods - Wiley

Figure 12: Resistance for a single core 16 A thermoplastic rated cable based in the a.c resistance at 50Hz of Cu thermoplastic V75/V90 PVC cable in conduit in air single phase amp from AS3008 Table 4 column 15 and Vc from table 41.



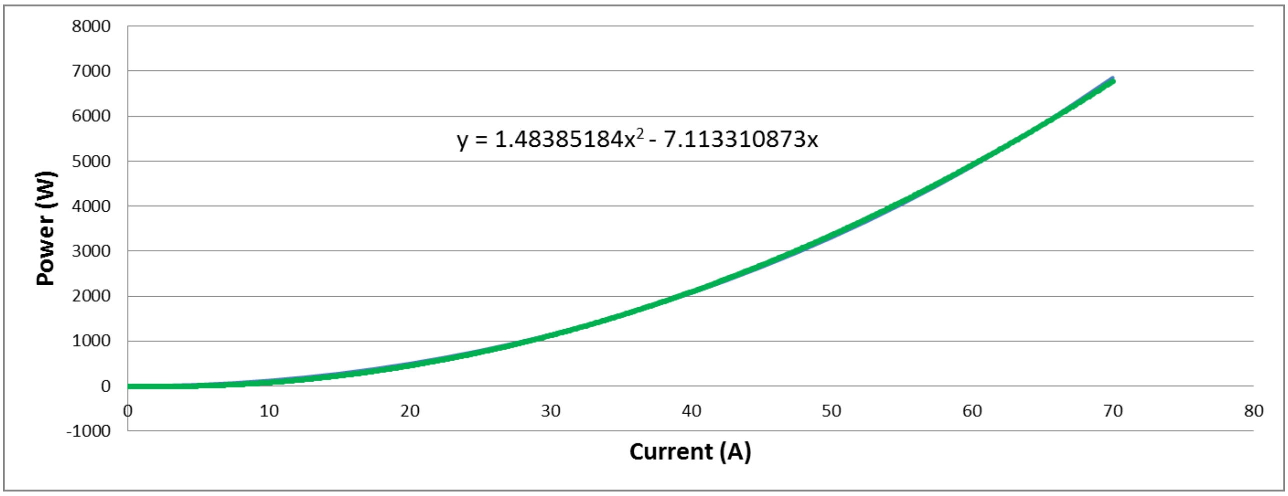
Source: AusEng analysis 2015.

Figure 13: Temperature for a single core 16 A thermoplastic rated cable based in the a.c resistance at 50Hz of Cu thermoplastic V75/V90 PVC cable in conduit in air single phase amp from AS3008 Table 4.



Source: AusEng analysis 2015.

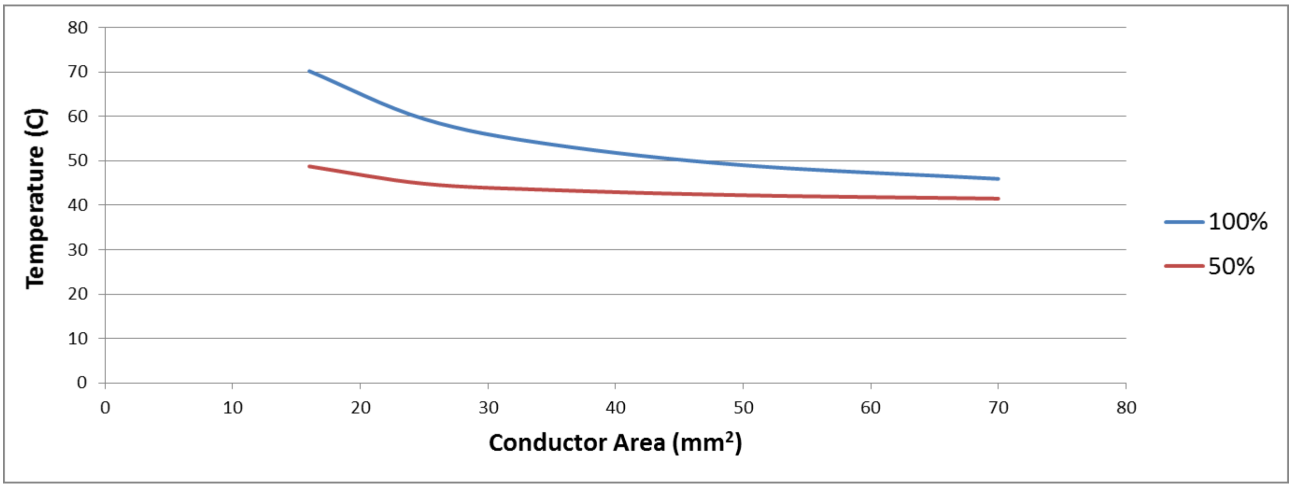
Figure 14: Power loss for a single core 16 A thermoplastic rated cable based in the a.c resistance at 50Hz of Cu thermoplastic V75/V90 PVC cable in conduit in air single phase amp from AS3008 Table 4.



Source: AusEng analysis 2015.

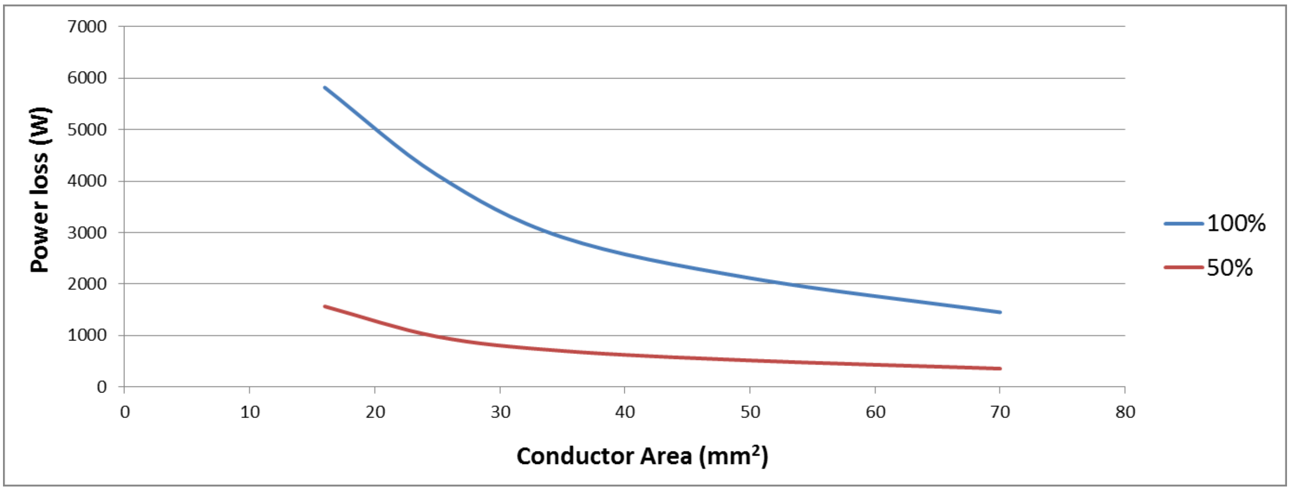
The following tables illustrate the reduction in conductor temperature and power loss with decreased operating temperature.

Figure 15: Temperature for a 100% (70A) and 50% (35A) load on single core thermoplastic V75/V90 PVC cable in conduit in air single phase amp from AS3008 Table 4, Column 15 from 16mm² to 70mm².



Source: AusEng analysis 2015.

Figure 16: Power loss for a 100% (70A) and 50% (35A) load on single core thermoplastic V75/V90 PVC cable in conduit in air single phase amp from AS3008 Table 4, Column 15 from 16mm² to 70mm².



Source: AusEng analysis 2015.

3.7.2 Busbars

Whilst busbars are not within scope of AS/NZS3008 and therefore not within the scope of this report the fundamental principles of improving net lifetime benefits through economic optimisation also apply to busbars. The process of determining optimal economic outcomes for cables and busbars requires a model of the electrical and thermal environments upon which to base the economic considerations. This model should include the costs of electrical losses, the cost of losses due to increased risk, reduced asset lifetime, additional air-conditioning requirements etc..

The complexities of determining the benefits of economically optimally sized cables were illustrated above (Sub Section 3.7.1) through one dimension of the necessary considerations for normal situations that are essentially a long thin conductor in an environment that is consistent for lengths of cable that are much greater than the cable diameter. Modelling of specific aspects of busbar thermal behaviour can be quite complex, particularly when considering the dynamic (transient loading) and steady state behaviours (see for example the analysis of Guru etc al[18]). Busbars can range from very short lengths that are found in switch gear to long lengths found in refineries. The energy balance of busbars that form part of a switchboard where the length of the bar is short and its terminations highly thermally conductive with forced air cooling will differ substantially from long vertical busbars with natural convective air cooling that may for example be found in a refinery.

Thus the challenge for determining economic busbar selection is establishing their thermal, electrical and economic characteristics over a large range of configurations and environments.

3.8 EXAMPLE 1 – ONE SIZE UPGRADE

This example is based on the calculations that were originally made for a typical 10 floor commercial installation. The original cable sizing represents current industry best practice. For the services being considered in this example the optimal ECS selected cables size are often several sizes larger than the safe cable size. However, in this example, the calculations are for only one size cable increase and only made if it is economically justified. The reason this was done was that it demonstrates how even a small increase in cable size can lead to substantial benefits. This approach has relevance when the cable's environment does not allow a full upgrade for example when a small duct is available and this simplified approach demonstrates many of the core principles and established the minimum benefits of ECS available for this site. The following section (3.9) demonstrates applying ECS to find the most economical cable size.

[18] Prediction of Temperature Rise in Busbars of Switchgear Using CFD, Gaurav Guru1, N P Gulhane, Kapil Bavikar, International Conference on Mechanical and Industrial Engineering, ISBN: 978-93-81693-89-6

Table 4: Example best practice installation (all three phase circuits).

Service	Circuit	length	Max Demand	Active/ phase	Neutral/ phase	Earth/ phase	Total Cost
		(m)	(A)	(mm^2)	(mm^2)	(mm^2)	($)
Consumer mains	1500kva KIOSK	20	2100	3*400	3*400	3*120	$13,450
SUBMAINS (SAFETY SERVICES)	MCCE-1	40	25	16	16	6	$757
	SPRINKLER PUMP	40	80	25	25	6	$1,047
	MCCE-2	80	160	50	50	16	$3,912
	LIFT 1	35	32	16	16	6	$663
	LIFT 2	75	63	16	16	6	$1,420
	LIFT 3	75	63	16	16	6	$1,420
	LIFT 4	75	63	16	16	6	$1,420
	LIFT 5	75	63	16	16	6	$1,420
	DB-FIRE	60	40	16	16	6	$1,136
SUBMAINS (NON-ESSENTIAL)	PFC	10	630	2*120	2*120	2*35	$1,151
	DB-BAR	50	250	95	95	25	$2,576
	DB-LOBBY	35	160	70	70	25	$1,319
	DB-G	15	160	70	70	25	$565
	MSSB	80	500	240	240	95	$9,309
	DB-RESTAURANT	60	250	95	95	25	$3,091
	DB-1	60	160	70	70	25	$2,262
	DB-2	50	400	240	240	95	$5,818
	DB-2	5	100	35	35	10	$93
	DB-3	3	400	240	240	95	$349
	DB-3	5	100	35	35	10	$93
	DB-4	3	400	240	240	95	$349
	DB-4	5	100	35	35	10	$93
	DB-5	3	400	240	240	95	$349
	DB-5	5	100	35	35	10	$93
	DB-ROOF	3	100	50	50	16	$78
	DB-6	38	400	240	240	95	$4,422
	DB-6	5	100	35	35	10	$93
	DB-7	3	400	240	240	95	$349
	DB-7	5	100	35	35	10	$93
	DB-COMMS	25	160	70	70	25	$942
	SOLAR PANELS	80	32	35	35	10	$1,495
	MCCN	30	100	35	35	10	$561

Source: AusEng 2015.

Table 5: Example best practice installation with single cable size upgrade where economically justified.

Service	Circuit	Economic Active	Economic Neutral	Economic Earth	Increased Total Cost	NPV	payback	B/C ratio	Abatement cost
		(mm²)	(mm²)	(mm²)	($)		(years)		($)
Consumer mains	1500kva KIOSK	500	500	120	$4,086	$18,833	2.1	5.6	-87
SUBMAINS (SAFETY SERVICES)	MCCE-1	25	25	6	$289	$353	6.0	2.2	-58
	SPRINKLER PUMP	35	35	10	$79	$3,869	0.2	49.9	-104
	MCCE-2	70	70	25	$393	$18,651	0.2	48.4	-104
	LIFT 1	25	25	6	$542	$8,707	0.7	17.1	-100
	LIFT 2	25	25	6	$542	$8,707	0.7	17.1	-100
	LIFT 3	25	25	6	$542	$8,707	0.7	17.1	-100
	LIFT 4	25	25	6	$542	$8,707	0.7	17.1	-100
	LIFT 5	25	25	6	$289	$353	6.0	2.2	-58
	DB-FIRE	25	25	6	$434	$2,175	1.9	6.0	-88
SUBMAINS (NON-ESSENTIAL)	PFC	150	150	50	$277	$4,585	0.6	17.5	-100
	DB-BAR	120	120	35	$648	$9,793	0.7	16.1	-99
	DB-LOBBY	95	95	25	$484	$4,605	1.1	10.5	-96
	DB-G	95	95	25	$207	$1,974	1.1	10.5	-96
	MSSB	300	300	120	$2,337	$22,275	1.1	10.5	-96
	DB-RESTAURANT	120	120	35	$777	$11,751	0.7	16.1	-99
	DB-1	95	95	25	$829	$7,894	1.1	10.5	-96
	DB-2	300	300	120	$1,461	$7,983	1.8	6.5	-90
	DB-2	50	50	16	$37	$489	0.8	14.3	-99
	DB-3	300	300	120	$88	$479	1.8	6.5	-90
	DB-3	50	50	16	$37	$489	0.8	14.3	-99
	DB-4	300	300	120	$88	$479	1.8	6.5	-90
	DB-4	50	50	16	$37	$489	0.8	14.3	-99
	DB-5	300	300	120	$88	$479	1.8	6.5	-90
	DB-5	50	50	16	$37	$489	0.8	14.3	-99
	DB-ROOF	70	70	25	$35	$196	1.8	6.6	-90
	DB-6	300	300	120	$1,110	$6,067	1.8	6.5	-90
	DB-6	50	50	16	$37	$489	0.8	14.3	-99
	DB-7	300	300	120	$88	$479	1.8	6.5	-90
	DB-7	50	50	16	$37	$489	0.8	14.3	-99
	DB-COMMS	95	95	25	$346	$3,289	1.1	10.5	-96
	SOLAR PANELS	50	50	16	$590	$94	15.1	1.2	-15
	MCCN	50	50	16	$221	$2,936	0.8	14.3	-99

Source: **AusEng 2015.**

3.9 EXAMPLE 2 – MOST ECONOMICAL UPGRADE

This example is similar to example 1 except that the most economical (greatest total NPV) was used to select the cable size.

Table 6: Example best practice installation with optimal economic cable sizing.

Service	Circuit	Economic Active	Economic Neutral	Economic Earth	Increased Total Cost	NPV	payback	B/C ratio	Abatement cost
		(mm²)	(mm²)	(mm²)	($)		(years)		($)
Consumer mains	1500kva KIOSK	500	500	120	$4,086	$18,833	2.1	5.6	-87
SUBMAINS (SAFETY SERVICES)	MCCE-1	35	35	10	$368	$584	5.0	2.6	-65
	SPRINKLER PUMP	70	70	25	$1,106	$7,062	1.6	7.4	-92
	MCCE-2	70	70	25	$393	$18,651	0.2	48.4	-104
	LIFT 1	50	50	16	$2,247	$13,516	1.7	7.0	-91
	LIFT 2	50	50	16	$2,247	$13,516	1.7	7.0	-91
	LIFT 3	50	50	16	$2,247	$13,516	1.7	7.0	-91
	LIFT 4	50	50	16	$2,247	$13,516	1.7	7.0	-91
	LIFT 5	35	35	10	$368	$584	5.0	2.6	-65
	DB-FIRE	35	35	10	$553	$3,478	1.6	7.3	-91
SUBMAINS (NON-ESSENTIAL)	PFC	240	240	95	$1,177	$10,592	1.1	10.0	-95
	DB-BAR	185	185	70	$2,410	$20,211	1.2	9.4	-95
	DB-LOBBY	150	150	50	$1,357	$7,674	1.7	6.7	-90
	DB-G	150	150	50	$581	$3,289	1.7	6.7	-90
	MSSB	500	500	120	$9,007	$47,120	1.9	6.2	-89
	DB-RESTAURANT	185	185	70	$2,892	$24,253	1.2	9.4	-95
	DB-1	150	150	50	$2,326	$13,155	1.7	6.7	-90
	DB-2	500	500	120	$5,629	$14,906	3.4	3.6	-77
	DB-2	95	95	25	$164	$986	1.7	7.0	-91
	DB-3	500	500	120	$338	$894	3.4	3.6	-77
	DB-3	95	95	25	$164	$986	1.7	7.0	-91
	DB-4	500	500	120	$338	$894	3.4	3.6	-77
	DB-4	95	95	25	$164	$986	1.7	7.0	-91
	DB-5	500	500	120	$338	$894	3.4	3.6	-77
	DB-5	95	95	25	$164	$986	1.7	7.0	-91
	DB-ROOF	120	120	35	$115	$351	3.0	4.0	-80
	DB-6	500	500	120	$4,278	$11,329	3.4	3.6	-77
	DB-6	95	95	25	$164	$986	1.7	7.0	-91
	DB-7	500	500	120	$338	$894	3.4	3.6	-77
	DB-7	95	95	25	$164	$986	1.7	7.0	-91
	DB-COMMS	150	150	50	$969	$5,481	1.7	6.7	-90
	SOLAR PANELS	50	50	16	$590	$94	15.1	1.2	-15
	MCCN	95	95	25	$985	$5,914	1.7	7.0	-91

Source: **AusEng 2015**.

3.10 SENSITIVITY TO ADDITIONAL CAPITAL COSTS

This section demonstrates the impact of additional upfront capital costs to the NPV. Upfront capital costs have two components, the cable costs and installation costs. Cable costs may depend on factors other than just conductor size, such as discounts for bulk purchases. Many of these “other” factors are situation dependant. In this report the 2012 retail value of cables is used. In practice the organisation applying the principles of economic cable sizing must use the costs and discount rates that are applicable to them. The installation costs are application specific and may range from zero to significantly more than the additional cost of the cable. Rather than produce a model with a limited set of predefined costs that generates results of limited scope, a sensitivity analysis has been undertaken that illustrates the key concepts.

For the purpose of explaining the results of the sensitivity analysis, the NVP equation that is derived in appendix C is repeated here:

$$\mathbf{NPV} = \frac{\mathbf{Y(1-(1+r)^{-n})}}{\mathbf{r}} - \mathbf{cc} \qquad \text{Equation 7}$$

An implication of Equation 6 is that “the greater the upfront capital cost from installing larger cable sizes relative to the NPV of energy savings, the greater the impact additional upfront capital costs will have on economic cable size”. In the cases reviewed, cable utilisation is high. Hence slight additional upfront capital costs have minimal impact upon the economic cable selection. Additional upfront capital costs would need to be quite large (several times the cost of the cable) to make the minimum cable size based on safety regulations the most economical cable size.

The results presented in Table 15 (for the AS3008 example 9) indicate that an increase in the cable size to 16mm^2-150mm^2 (based on the assumptions given) is economically justifiable (though not necessarily optimal) due to the relatively large NPV of energy savings, with an economically optimal cable size of 50mm^2. The Impact of an additional upfront capital cost that is 10% of the cable cost is demonstrated in Table 7. The economically optimal cable size does not change. An additional upfront cost of 10% reduces the total NPV by about 2% for a single increase in cable size. The 10% increase in additional upfront capital cost reduces the total NPV by less than 10% on cables that have conductor sizes smaller than 95mm^2. The Payback Periods and the Benefit to Cost ratios given in the two tables differ slightly for conductor size under 95mm^2. In this example, for conductor sizes under 95mm^2 it would require additional capital costs in the region of 1.3 to 4.8 times the additional cost of the selected cable (depending on the cable size selected) to make the increase in cable size uneconomical.

Table 7: Calculation results.

Conductor size	Cable cost	Other Capital Costs	Total Capital Costs	Cable losses	Cost of Losses pa*	Saving pa**	Total 20Y NPV	Decrease in total 20Y NPV	Payback Period	Benefit to cost ****	Capital Loss to make NPV=0*
(mm^2)	($)	($)	($)	(kW)	($)	($)	($)	(%)	(y)		(%)
16	355	36	391	0.207	272	-	-	-	-	-	-
25	537	54	591	0.131	172	100	$856	2.08%	2.2	4.3	480%
35	708	71	779	0.094	124	148	$1,177	2.91%	3.0	3.0	343%
50	964	96	1,060	0.066	87	185	$1,287	4.52%	4.3	1.9	221%
70	1,346	135	1,481	0.046	60	212	$1,151	7.93%	6.6	1.1	126%
95	1,832	183	2,015	0.033	44	228	$791	15.73%	10.2	0.5	64%
120	2,301	230	2,531	0.026	35	237	$370	34.44%	14.8	0.2	29%
150	2,856	286	3,142	0.022	28	243	-$173	324.81%	23.2**	-0.1	3%
185	3,564	356	3,920	0.017	23	249	-$893	-56.10%	72.8**	-0.3	-18%

Source: **AusEng 2013**

* Note the nonlinear step-like movements are due to how the earth cable size relates to the size of the active cable.
** Savings are based on difference from the 10mm^2 case (Step 1).
*** The investment is not paid back within 20 years.
**** Based only on increased cable costs and cost of energy saved.

In section 3.8 (EXAMPLE 1) and section 3.9 (EXAMPLE 2), the economic cable sizing model is applied to a commercial installation. An increase in at least one size cable size is economically justifiable for all circuits listed, with the given assumptions (results given in Table 4, Table 5, and Table 6). The impact of an additional upfront capital cost that is 10% of the cable cost is demonstrated in Table 7, Table 8 and Table 9. The impact of the additional upfront capital costs varies in magnitude depending on the circuit in the commercial installation, however, the economical optimal cable size does not change. The following general observations are made in regards to the implication of **Equation 7**:

- The larger the maximum demand of the circuit the greater the energy savings, the lesser the impact of the additional upfront costs (e.g. 1500kva Kiosk).
- The longer the cable the greater the energy savings, the lesser the impact of the additional upfront costs (e.g. Lifts 2-5).

Opposing effects may vary in magnitude (such as large maximum demand and short cable length) and do not necessarily cancel out. For example, while the Solar Panel circuit consists of a long cable length, it has a relatively low maximum demand that makes its economic cable size susceptible to small changes in additional upfront capital costs.

Table 8: Example best practice installation with single cable size upgrade where economically justified including an additional upfront capital cost that is 10% of the Cost of Cable.

Service	Circuit	Increased Cable Cost	Increased Other Capital Costs	Increased Total Cost	NPV without increase in Other Capital Costs	NPV with increase in Other Capital Costs	Payback without increase in Other Capital Costs	Payback with increase in Other Capital Costs	B/C ratio without increase in Other Capital Costs	B/C ratio with increase in Other Capital Costs	Abatement cost without increase in Other Capital Costs	Abatement cost with increase in Other Capital Costs
		($)	($)	($)	($)	($)	(years)	(years)			($)	($)
Consumer mains	1500kva KIOSK	$4,086	$409	$4,494	$18,833	$18,425	2.1	2.3	5.6	5.1	-87	-85
SUBMAINS (SAFETY SERVICES)	MCCE-1	$289	$29	$318	$353	$324	6.0	6.8	2.2	2.0	-58	-53
	SPRINKLER PUMP	$79	$8	$87	$3,869	$3,861	0.2	0.2	49.9	45.3	-104	-104
	MCCE-2	$393	$39	$432	$18,651	$18,612	0.2	0.3	48.4	44.0	-104	-104
	LIFT 1	$542	$54	$596	$8,707	$8,652	0.7	0.7	17.1	15.5	-100	-99
	LIFT 2	$542	$54	$596	$8,707	$8,652	0.7	0.7	17.1	15.5	-100	-99
	LIFT 3	$542	$54	$596	$8,707	$8,652	0.7	0.7	17.1	15.5	-100	-99
	LIFT 4	$542	$54	$596	$8,707	$8,652	0.7	0.7	17.1	15.5	-100	-99
	LIFT 5	$253	$25	$278	$807	$781	2.9	3.2	4.2	3.8	-81	-78
	DB-FIRE	$434	$43	$477	$2,175	$2,131	1.9	2.2	6.0	5.5	-88	-87
SUBMAINS (NON-ESSENTIAL)	PFC	$277	$28	$305	$4,585	$4,557	0.6	0.7	17.5	15.9	-100	-99
	DB-BAR	$648	$65	$712	$9,793	$9,728	0.7	0.8	16.1	14.7	-99	-99
	DB-LOBBY	$484	$48	$532	$4,605	$4,557	1.1	1.2	10.5	9.6	-96	-95
	DB-G	$207	$21	$228	$1,974	$1,953	1.1	1.2	10.5	9.6	-96	-95
	MSSB	$2,337	$234	$2,571	$22,275	$22,041	1.1	1.2	10.5	9.6	-96	-95
	DB-RESTAURANT	$777	$78	$855	$11,751	$11,674	0.7	0.8	16.1	14.7	-99	-99
	DB-1	$829	$83	$912	$7,894	$7,812	1.1	1.2	10.5	9.6	-96	-95
	DB-2	$1,461	$146	$1,607	$7,983	$7,837	1.8	2.0	6.5	5.9	-90	-88
	DB-2	$37	$4	$41	$489	$486	0.8	0.9	14.3	13.0	-99	-98
	DB-3	$88	$9	$96	$479	$470	1.8	2.0	6.5	5.9	-90	-88
	DB-3	$37	$4	$41	$489	$486	0.8	0.9	14.3	13.0	-99	-98
	DB-4	$88	$9	$96	$479	$470	1.8	2.0	6.5	5.9	-90	-88
	DB-4	$37	$4	$41	$489	$486	0.8	0.9	14.3	13.0	-99	-98
	DB-5	$88	$9	$96	$479	$470	1.8	2.0	6.5	5.9	-90	-88
	DB-5	$37	$4	$41	$489	$486	0.8	0.9	14.3	13.0	-99	-98
	DB-ROOF	$35	$3	$38	$196	$192	1.8	1.9	6.6	6.0	-90	-88
	DB-6	$1,110	$111	$1,221	$6,067	$5,956	1.8	2.0	6.5	5.9	-90	-88
	DB-6	$37	$4	$41	$489	$486	0.8	0.9	14.3	13.0	-99	-98
	DB-7	$88	$9	$96	$479	$470	1.8	2.0	6.5	5.9	-90	-88
	DB-7	$37	$4	$41	$489	$486	0.8	0.9	14.3	13.0	-99	-98
	DB-COMMS	$346	$35	$380	$3,289	$3,255	1.1	1.2	10.5	9.6	-96	-95
	SOLAR PANELS	$590	$59	$649	$94	$35	15.1	18.0	1.2	1.1	-15	-5
	MCCN	$221	$22	$243	$2,936	$2,914	0.8	0.9	14.3	13.0	-99	-98

Source: **AusEng 2015.**

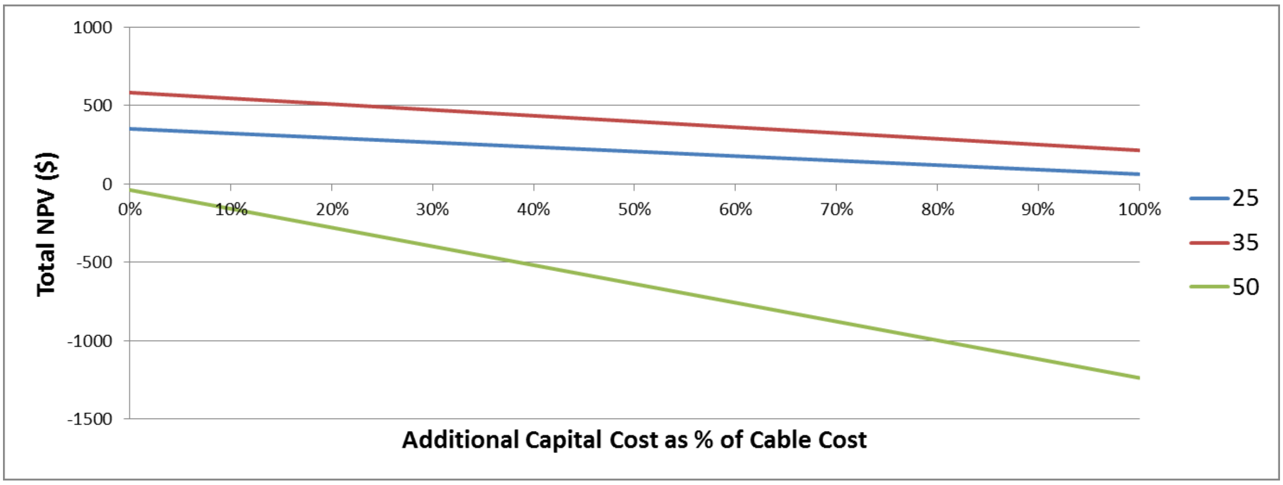
Table 9: Example best practice installation with optimal economic cable sizing where economically justified including an additional upfront capital cost that is 10% of the Cost of Cable.

Service	Circuit	Increased Cable Cost	Increased Other Capital Costs	Increased Total Cost	NPV without increase in Other Capital Costs	NPV with increase in Other Capital Costs	Payback without increase in Other Capital Costs	Payback with increase in Other Capital Costs	B/C ratio without increase in Other Capital Costs	B/C ratio with increase in Other Capital Costs	Abatement cost without increase in Other Capital Costs	Abatement cost with increase in Other Capital Costs
		($)	($)	($)	($)	($)	(years)	(years)			($)	($)
Consumer mains	1500kva KIOSK	$4,086	$409	$4,494	$18,833	$18,425	2.1	2.3	5.6	5.1	-87	-85
SUBMAINS (SAFETY SERVICES)	MCCE-1	$368	$37	$405	$584	$547	5.0	5.6	2.6	2.3	-65	-61
	SPRINKLER PUMP	$1,106	$111	$1,216	$7,062	$6,952	1.6	1.7	7.4	6.7	-92	-90
	MCCE-2	$393	$39	$432	$18,651	$18,612	0.2	0.3	48.4	44.0	-104	-104
	LIFT 1	$2,247	$225	$2,472	$13,516	$13,291	1.7	1.8	7.0	6.4	-91	-89
	LIFT 2	$2,247	$225	$2,472	$13,516	$13,291	1.7	1.8	7.0	6.4	-91	-89
	LIFT 3	$2,247	$225	$2,472	$13,516	$13,291	1.7	1.8	7.0	6.4	-91	-89
	LIFT 4	$2,247	$225	$2,472	$13,516	$13,291	1.7	1.8	7.0	6.4	-91	-89
	LIFT 5	$322	$32	$355	$1,182	$1,150	2.6	2.8	4.7	4.2	-83	-81
	DB-FIRE	$553	$55	$608	$3,478	$3,423	1.6	1.8	7.3	6.6	-91	-90
SUBMAINS (NON-ESSENTIAL)	PFC	$1,177	$118	$1,294	$10,592	$10,474	1.1	1.3	10.0	9.1	-95	-94
	DB-BAR	$2,410	$241	$2,651	$20,211	$19,970	1.2	1.3	9.4	8.5	-95	-94
	DB-LOBBY	$1,357	$136	$1,492	$7,674	$7,538	1.7	1.9	6.7	6.1	-90	-88
	DB-G	$581	$58	$640	$3,289	$3,231	1.7	1.9	6.7	6.1	-90	-88
	MSSB	$9,007	$901	$9,908	$47,120	$46,220	1.9	2.1	6.2	5.7	-89	-87
	DB-RESTAURANT	$2,892	$289	$3,181	$24,253	$23,964	1.2	1.3	9.4	8.5	-95	-94
	DB-1	$2,326	$233	$2,558	$13,155	$12,922	1.7	1.9	6.7	6.1	-90	-88
	DB-2	$5,629	$563	$6,192	$14,906	$14,343	3.4	3.7	3.6	3.3	-77	-74
	DB-2	$164	$16	$181	$986	$969	1.7	1.8	7.0	6.4	-91	-89
	DB-3	$338	$34	$372	$894	$861	3.4	3.7	3.6	3.3	-77	-74
	DB-3	$164	$16	$181	$986	$969	1.7	1.8	7.0	6.4	-91	-89
	DB-4	$338	$34	$372	$894	$861	3.4	3.7	3.6	3.3	-77	-74
	DB-4	$164	$16	$181	$986	$969	1.7	1.8	7.0	6.4	-91	-89
	DB-5	$338	$34	$372	$894	$861	3.4	3.7	3.6	3.3	-77	-74
	DB-5	$164	$16	$181	$986	$969	1.7	1.8	7.0	6.4	-91	-89
	DB-ROOF	$115	$12	$127	$351	$339	3.0	3.3	4.0	3.7	-80	-77
	DB-6	$4,278	$428	$4,706	$11,329	$10,901	3.4	3.7	3.6	3.3	-77	-74
	DB-6	$164	$16	$181	$986	$969	1.7	1.8	7.0	6.4	-91	-89
	DB-7	$338	$34	$372	$894	$861	3.4	3.7	3.6	3.3	-77	-74
	DB-7	$164	$16	$181	$986	$969	1.7	1.8	7.0	6.4	-91	-89
	DB-COMMS	$969	$97	$1,066	$5,481	$5,384	1.7	1.9	6.7	6.1	-90	-88
	SOLAR PANELS	$590	$59	$649	$94	$35	15.1	18.0	1.2	1.1	-15	-5
	MCCN	$985	$98	$1,083	$5,914	$5,816	1.7	1.8	7.0	6.4	-91	-89

Source: **AusEng 2015.**

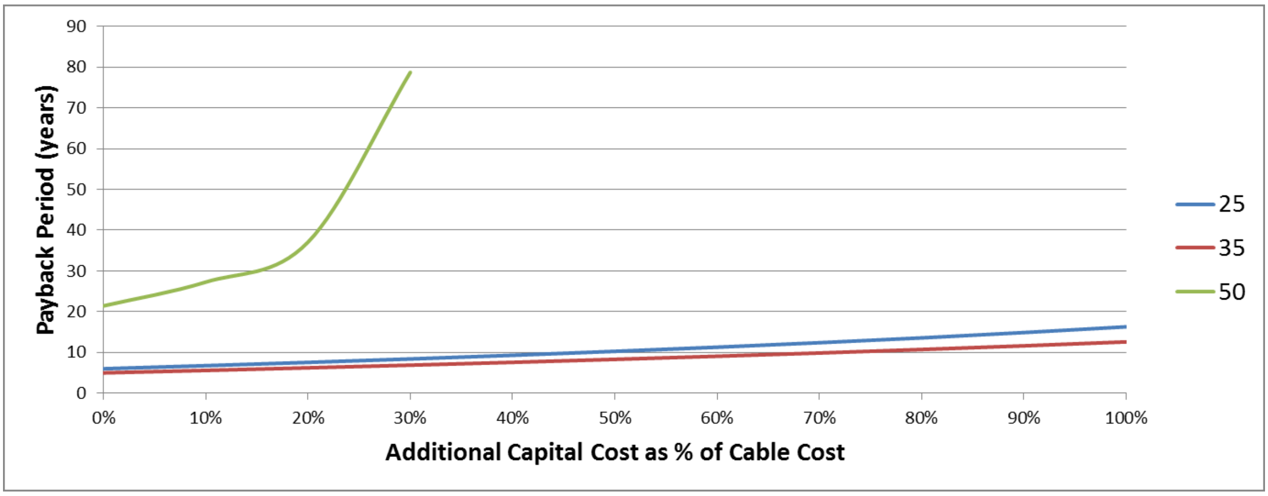
The economic cable size depends on the additional upfront capital costs. In this sensitivity analysis the additional upfront capital costs are assumed to be a percentage of the cable cost. Hence, the larger the cable the larger the additional upfront capital costs. In practice the organisation applying the principles of economic cable sizing must use the additional upfront capital costs that are applicable to them. In **Table 9**, the mcce-1 circuit (without additional upfront capital costs) has an economically optimal size of 35mm^2. Even when the additional upfront capital costs are 100%, 35mm^2 remains the economically optimal size (see **Figure 17**). Note the 35mm^2 cable loses NPV at a faster rate than the 25mm^2 cable as the cost of 35mm^2 cable increases at a faster rate. As the additional upfront capital costs increase, the economically optimal cable size decreases until the cable size based on safety is selected. Usually the decrease in size selected is in a linear order, however there are steps in the total NPV due to earthing requirements which mean certain cable sizes will be skipped. In **Table 4**, circuit MCCE-1, the 35mm^2 cable is the economically optimal cable size, for the given set of assumptions (and no additional upfront costs). **Figure 18** demonstrates the impact of increasing upfront capital costs on the NPV, and hence the economically optimal cable size. The 35mm^2 cable remains favourable over the 25mm^2 cable, until after the 16mm safety based cable becomes optimal.

Figure 17: Total NPV for a range of additional upfront capital costs, for cable sizes 25mm^2, 35mm^2 and 50mm.



Source: AusEng analysis 2015.

Figure 18: Total NPV for MCCE-GF-1 for a range of additional upfront capital costs, for cable sizes 25mm^2, 35mm^2 and 50mm^2.



Source: AusEng analysis 2015.

3.11 ELECTRICITY PRICES

The benefits of economic cable sizing are directly related to the retail price of electricity. For a study such as this, at least four pricing dimensions need to be considered:

- Cost across jurisdictions and national averages;
- Short term pricing (daily);
- Change in pricing over the longer time periods (asset lifetimes) considered; and
- How these pricings reflect regional and global prices.

Because there is no or little information on when loads are used and there are many regional differences in pricing, a year has passed since the data were collected, and a general uncertainty in determining true commercial electricity prices, in this report the cost of electricity is conservatively set at 20c/kWh - see Price of Electricity in Australia, AusEng 2011" for detailed pricing analysis.

3.12 EMBODIED ENERGY

The broader environmental questions of using more copper include accounting for the extra embodied energy which is the total life cycle energy used to create and dispose of a product. For copper it includes the electrical energy that is used to extract and refine the copper, manufacture the wire and dispose of or recycle it. The embodied energy of copper obviously depends on the type of energy sources used in its lifecycle. In this analysis, copper's embodied energy is taken from data published in 2005 which indicates that it has a relatively low embodied energy of about 70 MJ/kg compared to Aluminium with 220 MJ/kg. This total includes the energy used to make the copper, which in Germany the entire production chain up to the production of 1 kg is shown in **Table 10**. Japanese producers of copper report between 1400 to 2200 kg of CO_2-e are produced to make 1 kg of Copper[19]. Thus the carbon values depend on the material composition and energy source CO_2-e intensities which in Australia are 1kg/kWh.

Table 10: Embodied energy and CO_2-e to make 1kg of copper in Germany.

	without recycling	**with recycling**	**50%/50% mix of new and recycled copper**
MJ/kg	70.46	27.16	48.89
Kg CO_2-e	5.62	1.92	3.77

Source: **German 2005 data (Source: Metal production, Morten Simonsen Vestlandsforsking, 5 April 2009)**

The embodied energy is compared to the equivalent CO_2-e reduction over a 20 year period for each cable set is given in **Table 11**. It can be seen that the embodied energy is usually very small compared to the savings and further support the case for economic sizing.

[19] **Metal production, Morten Simonsen Vestlandsforsking, 5 April 2009.**

Table 11: Embodied CO_2-e per kg (using maximum value of 5.62) and CO_2-e saved over a 20 year period.

Service	Circuit	Economic Active	Economic Neutral	Economic Earth	Increase in Cu	Extra embodied CO_2-e to produce extra Cu	Embodied CO_2-e / CO_2-e saved over 20y
		(mm^2)	(mm^2)	(mm^2)	(kg)	(kg)	(%)
Consumer mains	1500kva KIOSK	500	500	120	214	1204	0.56%
SUBMAINS (SAFETY SERVICES)	MCCE-1	35	35	10	15	84	0.94%
	SPRINKLER PUMP	70	70	25	39	219	0.28%
	MCCE-2	70	70	25	35	197	0.11%
	LIFT 1	50	50	16	52	294	0.20%
	LIFT 2	50	50	16	52	294	0.20%
	LIFT 3	50	50	16	52	294	0.20%
	LIFT 4	50	50	16	52	294	0.20%
	LIFT 5	35	35	10	15	84	0.94%
	DB-FIRE	35	35	10	23	126	0.33%
SUBMAINS (NON-ESSENTIAL)	PFC	240	240	95	75	422	0.38%
	DB-BAR	185	185	70	100	565	0.26%
	DB-LOBBY	150	150	50	58	325	0.38%
	DB-G	150	150	50	25	139	0.38%
	MSSB	500	500	120	389	2188	0.41%
	DB-RESTAURANT	185	185	70	121	678	0.26%
	DB-1	150	150	50	99	557	0.38%
	DB-2	500	500	120	243	1368	0.71%
	DB-2	95	95	25	6	34	0.31%
	DB-3	500	500	120	15	82	0.71%
	DB-3	95	95	25	6	34	0.31%
	DB-4	500	500	120	15	82	0.71%
	DB-4	95	95	25	6	34	0.31%
	DB-5	500	500	120	15	82	0.71%
	DB-5	95	95	25	6	34	0.31%
	DB-ROOF	120	120	35	4	24	0.54%
	DB-6	500	500	120	185	1039	0.71%
	DB-6	95	95	25	6	34	0.31%
	DB-7	500	500	120	15	82	0.71%
	DB-7	95	95	25	6	34	0.31%
	DB-COMMS	150	150	50	41	232	0.38%
	SOLAR PANELS	50	50	16	26	145	2.24%
	MCCN	95	95	25	36	203	0.31%

Source: **AusEng 2015**.

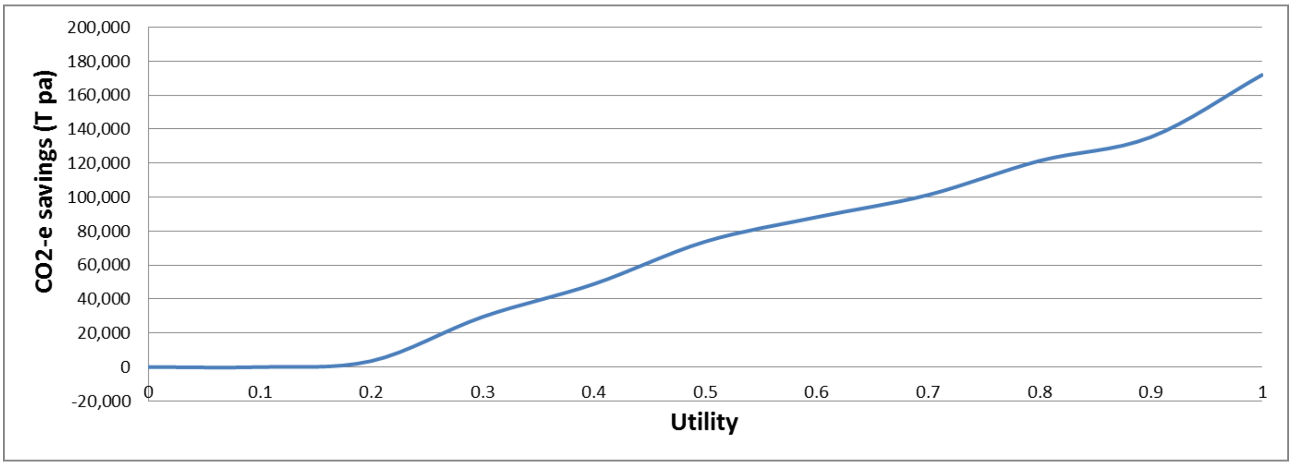
3.13 ENVIRONMENT

The annual greenhouse gas abatement is projected to be about 0.306MT (**Figure 20**) with the cost of abatement up to -$82.9 (**Figure 23**). This is similar both in impact and cost to the commercial lighting efficiency scheme (**Figure 21**). The environmental impact of adopting economic cable sizing for commercial buildings is somewhat modest, but sufficient for those seeking green credentials or are environmentally conscious - the impact is equivalent to removing 34MW of generation from the electricity supply system. This assessment may change as better information becomes available a clearer picture emerges.

3.13.1 CO_2-e reduction

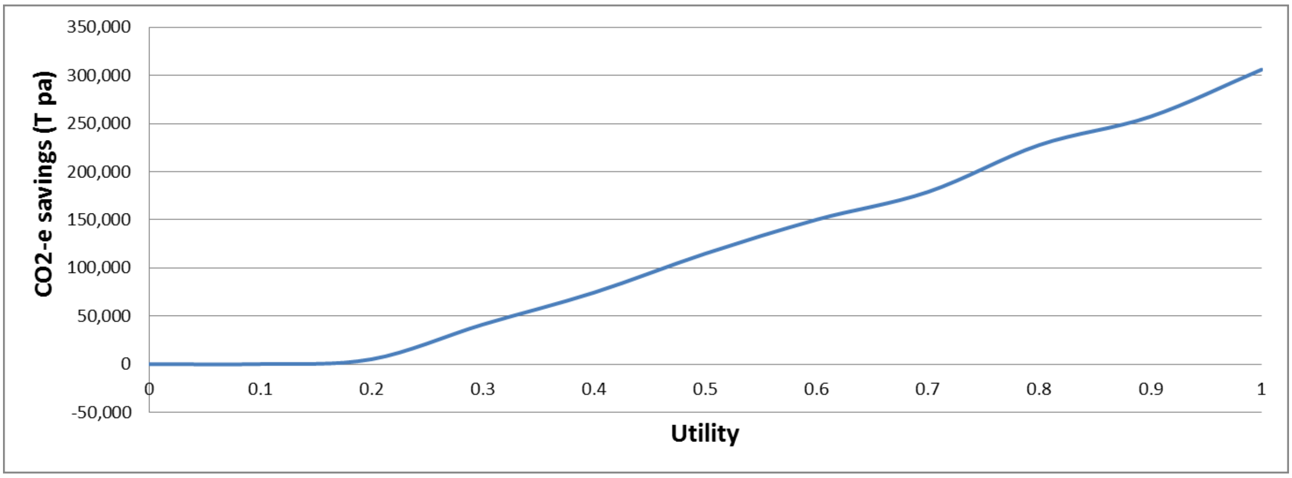
The following two figures show the dependence of the potential CO2-e savings on utility for the single and optimal ECS upgrade. For both cases there is little benefit until the utility exceeds 0.2.

Figure 19: Single size ECS upgrade: CO_2-e annual savings.



Source: AusEng analysis 2015.

Figure 20: Optimal ECS: CO_2-e annual savings.

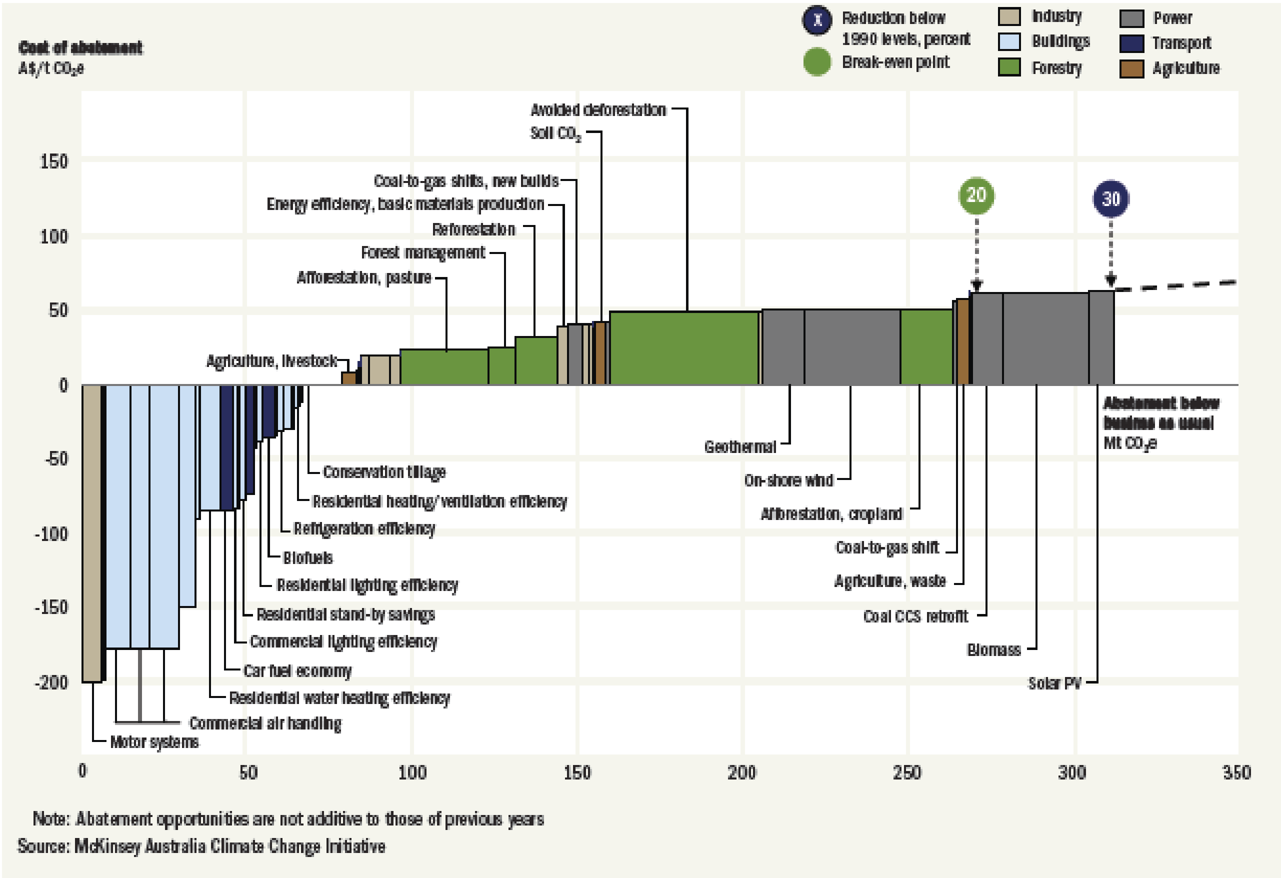


Source: AusEng analysis 2015.

3.13.2 Abatement cost

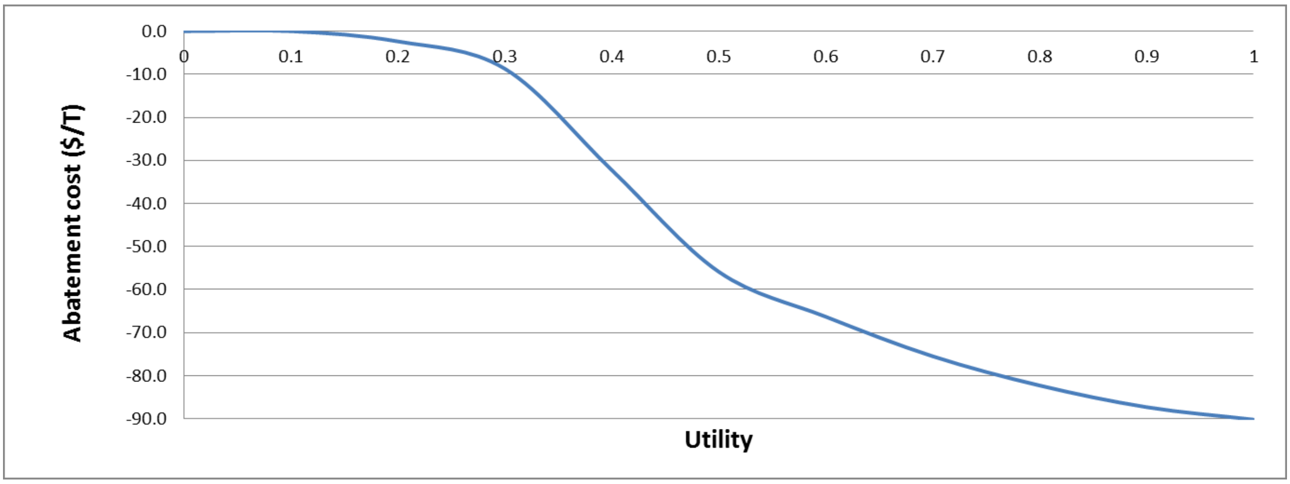
One of the measures governments and their agencies use to rank various initiatives is the cost borne to remove the carbon. **Figure 21** shows a very common representation of the options that are available to governments that in this case was provided by McKinsey. **Figure 22** and **Figure 23** show how the abatement due to ECS changes with utility.

Figure 21: Australian 2020 carbon abatement cost curve.



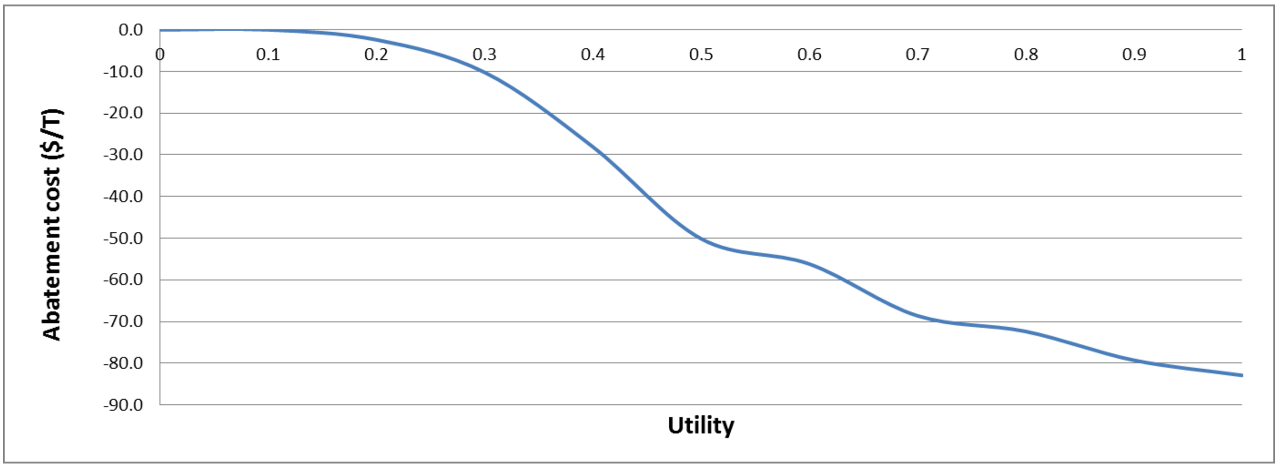
Source: An Australian Cost Curve for Greenhouse Gas Reducation, McKinsey 2008.

Figure 22: Single size ECS upgrade: Dependence of the cost of abatement on cable utility for the situation given in the example.



Source: AusEng analysis 2015.

Figure 23: Optimal ECS: Dependence of the cost of abatement on cable utility for the situation given in the example.



Source: AusEng analysis 2015.

4 EXAMPLE OF ECS APPLIED TO EXAMPLE 4, APPENDIX 4, AS/NZS 3008

This section describes the process of applying economic cable sizing to example A4 in AS3008. It has been provided to augment the material provided in example A9 of AS/NZS3008.

4.1 ECONOMIC CABLE SIZING

The principle of economic cable sizing is to select a cable size of minimum admissible cross-sectional area that is safe to use and where the cost of the losses that will occur during the life of the cable are minimised. This objective is met by optimising the present value of upfront costs and cost savings that are due to lifetime savings for the electricity consumer. Such cable must always be of greater cross-sectional area than one that is selected through the application of the normal safety based processes explained elsewhere in this and other standards.

The process of selecting a cable size that is based on economic arguments has seven main steps which are illustrated below.

Results are sensitive to input parameters such as cost of electricity, cable and installation and care must be taken to ensure that all data is appropriate for each installation.

The beneficiary, in this example, is assumed to be the entity that pays for both the cable and the electricity bill for an economically sufficient period.

4.2 EXISTING MATERIAL

4.2.1 Problem (A4.1)

Six four-core V-75 insulated and sheathed copper cables are arranged touching in a single horizontal row on a perforated cable tray for the supply of six identical 22 kW motors which have a full-load current of 45 A per phase and are installed at distances of 40 m, 55 m, 90 m, 135 m, 180 m and 225 m from the origin of the cable tray. Determine the minimum conductor size if a voltage drop of 2.4 % (10 V) is permitted for each cable.

4.2.2 Solution

The selection of conductor size in this instance must satisfy both the current-carrying capacity requirement, including the effect of the cables being grouped, and the voltage drop limitation.

The cable sizes required to satisfy the voltage drop restriction are assessed using the formula of Clause 4.2 (of AS/NZS3008, the actual load current of 45A, the permissible voltage drop V_d of 10 V and the three-phase voltage drop figures of Table 42 (of AS/NZS3008). The results of these calculations, the current-carrying capacity given in Table 13 (of AS/NZS3008) and its ratio to the load current, are given in Table 12.

Table 12: Calculation results.

Cable	Length	Maximum Vc	Minimum cable size	Maximum current-carrying capacity	Ratio of actual load current to max. current-carrying capacity of cable
	m	mV/A.m.	mm²	A	
A	40	5.56	10	51	0.88
B	55	4.04	10	51	0.88
C	90	2.47	16	68	0.66
D	135	1.65	25	91	0.49
E	180	1.23	35	112	0.40
F	225	0.98	50	137	0.33

Source: **AS3008.**

4.3 CALCULATION DETAILS

4.3.1 STEP 1. Basic information

Using normal practice of considering current-carrying capacity and voltage drop requirements, the initial cross sectional area of conductor is selected. For this example, such practice gives a 16mm² conductor. The cables considered for economic optimisation in this example are nominal sizes with conductors ranging in cross sectional area from 16mm² to 630mm², but this does not preclude the use of other cross-sectional areas including those achieved with combinations of conductors that are connected in parallel.

The utility represents the percentage of daily use and the current expressed as a fraction of the maximum demand. In this example the utility is set at full time use and 80% of the maximum demand current. Since losses are proportional to the square of current, if the current is not the maximum demand then the losses will be lower leading to a conservative value for the optimal conductor size.

The initial information is summarised in the **Table 13** below:

Table 13: Summary of information.

Max Demand	Conductor cross sectional area	Maximum voltage drop	Route length	Utility
(A)	(mm²)	(V)	(m)	(%)
45	16*	10	40	80

Source: **AusEng 2013.**

Notes:

*** Selected according to normal practices (note that in the example the 10^2 mm minimum cable size that is selected by Maximum Current Rating requirements is increased to 16mm² when derating factors for circuits are taken into account.**

4.3.2 STEP 2. Calculate phase conductor operating temperature and a.c. resistance

The challenge in this step is to determine the ac resistance of the cable so we can work out the losses. To do this we need to know the cable temperature. There are two ways to do this, firstly to use the actual current or use the maximum allowable current. Here we use the actual current.

Column 5 of Table 13 provides the current rating. For a four core copper 16mm² v-75 cable, the current rating is 68A. However, due to the way the cable is laid, column 9 of Table 24 indicates a derating factor of 0.76 applies. The adjusted current rating of the cable is the multiple of the current rating and the derating factor. For the four core copper 16mm² v-75 cable, the adjusted current rating is 68 A x 0.76 = 51.68 A.

Note: It is important not to confuse the adjusted current rating (51.68 A) that is used to work out the cable resistance for the (45A) with the minimum current-carrying capacity (59.2 A) that is worked out in example 4 that si the maximum current eh bunched 16mm² cable is permitted to carry.

For further clarification, the first case (adjusted current rating) refers to a single stand-alone cable rated at 68A at 75°C and the task is to determine what the current rating is of the same cable when it is in a bunch.

$$I_{bunched} = RF * I_{single} \quad \text{Equation 8}$$

Where,

$I_{bunched}$ is the rating of the cable when bunched,

I_{single} is the rating when the cable is on its own, and

RF is the rating factor.

Thus, the bunched rating is 0.76*68 = 51.58 A

The second case is related to the minimum current-carrying capacity required if we have a bunch of cables that must carry 45A then what is the equivalent current in a single cable. It is 45/0.76 = 59.21A. This is the value used in example 4 of AS/NZS3008 to determine the minimum allowable cable size, not the temperature that will result from having 45A passed through it. To answer this question we must use the data from Table 35, Column 3 that is for a standalone cable that is equivalent to the 45A in a bunched situation.

Armed with the above clarifications, the phase conductor temperature (θ_0) is estimated by using **Equation 4**.The calculated temperature is then raised to the nearest temperature 45°C, 60°C, 75°C, 80°C, 90°C or 110°C for use in determining the conductor a.c. resistance with Table 35 of AS/NZS3008 (as the cable is multicore).

$$\left(\frac{45\times 80\%}{51.68}\right)^2 = \frac{\theta_0 - 40}{75-40}$$

θ_0 = 57°C, raised to 60°C.

Therefore the a.c. resistance of the 16 mm² is 1.33 Ω/km (Table 35, Column 3).

The a.c. resistance for a route length of 40m = 1.33 x 0.04 = 0.0532 Ω.

4.3.3 STEP 3. Calculate I^2R loss of the cable

At 100% utility (a current of 45A and 100% use), the I^2R loss of the cable is calculated as follows:

$I^2R = 45^2 \times 0.0532$ = 108 W per phase or 323 W for three-phase.

Where,

I = current flowing in the conductor, in amperes, and

R = a.c. resistance of the conductor, in ohms.

At 80% utility (a current of 36 A), the I^2R loss of the cable is calculated as follows:

$I^2R = (80\% \times 45)^2 \times 0.0532$ = 69 W per phase or 207 W for three phases. **Equation 9**

Where,

I = current flowing in the conductor, in amperes, and

R = a.c. resistance of the conductor, in ohms.

The a.c. resistance of the conductor is lower when the utility is 80% because the conductor temperature is lower.

In this example the unit cost of electricity is assumed to be 15 c/kWh. The annual cost of 207 W is therefore:

0.207 x 0.15 x 24 x 365 = $272.

The above steps are to be repeated for all cable sizes considered in the example.

Table 14: Summary of Calculations

1	2	3	4		5	6	7	8	9	10
Phase conductor size	Earth conductor size §	Cable cost (4 core plus earth)*	Current rating †	Adjusted current rating	Phase conductor temperature	Increase in cable cost over cost of 95mm² cable	a.c resistance of phase conductor ‡	I²R loss of cable (3 phase)	Cost of I²R loss	Saving in cost of I²R loss from cost of 16mm² cable
						(cc)				(Y)
mm²	mm²	$	A	A	°C	$	Ω	kW	$/yr	$
16	6	355	68	51.68	57	-	0.0532	0.207	272	-
25	6	537	91	69.16	49	182	0.03368	0.131	172	100
35	10	708	112	85.12	46	353	0.02428	0.094	124	148
50	16	964	137	104.12	44	609	0.01704	0.066	87	185
70	25	1,346	172	130.72	43	991	0.0118	0.046	60	212
95	25	1,832	213	161.88	42	1,477	0.00856	0.033	44	228
120	35	2,301	247	187.72	41	1,946	0.0068	0.026	35	237

Source: **AusEng 2015.**

Notes:

§ Earth size as per AS/NZS3000:2007 Table 5.1.
*** Indicative cost of 4c+e (priced as separate cables due to size requirements) only. Additional installation and other costs, if incurred, may be added to these numbers.**
† Table 13, Column 5.
‡ Table 35, Column 2 to Column 5 and adjusted for a route length of 40m.

4.3.4 STEP 4. Calculation of the Net Present Value

The Net Present Value is the difference between the present value of savings in the cost of I^2R loss over the time period and the increase in capital expenditure.

The total NPV is given by

$$NPV_{total} = NPV_{savings} - cc$$ Equation 10

Where,

$NPV_{savings}$ = net present value of savings in the cost of I^2R loss over the same time period, $,

NPV_{total} = the net present value of the total cost over the time period is the difference between the net present value of savings in the cost of I^2R loss over the same time period and the increase in capital expenditure, $, and

cc = increase in capital expenditure, $, i.e. additional cable cost and other upfront costs, as a result of using a larger cable in today's value.

Note: see APPENDIX A for further information.

The $NPV_{savings}$ can be expanded to give the following equation for the NPV_{total}.

$$NPV_{total} = \frac{Y(1-(1+r)^{-n})}{r} - cc$$ Equation 11

Where,

n = time period, years = 20 years [see Note 1],

r = discount rate, % = 7% see Note 2, and

Y = savings in cost of I^2R loss (a cash flow) as a result of using a larger cable, $/year see Note 3.

Notes:

n **is assumed to be the time period the entity that pays the capital costs accrues benefits from the savings due to that investment. For a domestic situation this time period is the average time first home owners stay in the home (~7 years). An appropriate time period should be used for commercial installations. In this commercial or industrial example the time period is assumed to be 20 years. If the calculated payback period is longer than 20 years then the cable size will not be economically viable. The time period (*n*) is not to be confused with the payback period (*N*), which is a particular instance of *n* when the NPV_{total} is equal to 0.**

[2] The discount rate (*r*) is the expected rate of return that those paying for the energy losses (home or building owner) could earn for a similar risk in financial markets. In this example it has been set to 7% (expressed as 0.07, not 1.07).

[3] Value of annual energy savings from reduced I^2R loss – unit cost of electricity is assumed to be constant for the time period.

[4] The Microsoft Excel spreadsheet *NPV* function is not used as it does not allow for constant cash flows over a set period of time. The Excel *NPV* function requires each year's cash flow to be worked out and entered separately into the function.

Equation 11 can be solved to determine the NPV_{total} of moving up one cable size to 25mm^2:

$$NPV_{total} = \frac{100(1-(1+0.07)^{-20})}{0.07} - 182 = \$874$$

Note: The way the intermediate results are rounded may influence the NPV_{total}. For example if the rounded values of 100 and 182 are used NPV_{total} is \$877. When unrounded numbers are used the NPV_{total} is \$874**.**

4.3.5 STEP 5. Calculation of the payback period

The payback period (N) represents the number of years that the accumulated savings of reduced losses equals the additional cost of installing a larger cable size. The payback period is determined when the NPV_{total} is equal to 0. By using equation Equation 11 and making the NPV_{total} equal to zero:

$$NPV_{total} = \frac{Y(1-(1+r)^{-n})}{r} - cc$$

$$0 = \frac{Y(1-(1+r)^{-n})}{r} - cc$$

The above can be rewritten as:

$$N = \frac{-log\left(1 - \frac{r * cc}{Y}\right)}{log(1+r)} \qquad \text{Equation 12}$$

Where,

N = payback period, years.

As a result of moving one cable size up to 25mm^2:

$Y = 272 - 172 = \$100$, and

$cc = 537 - 355 = \$182$

The payback period (N) in this example is therefore:

$$N = \frac{-\log\left(1 - \frac{0.07 * 182}{100}\right)}{\log(1+0.07)} = 2.0\ years.$$ **Equation 13**

The benefit to cost (B/C) ratio for moving one cable size up to 25mm²:

$$\frac{B}{C} = \frac{NPV}{cc}$$ **Equation 14**

B/C = 874 / 182 = 4.8

Note: The benefit to cost ratio is used as both a ranking indicator and a decision threshold. B/C ratio should be significantly greater than one for the investment to worthwhile. The benefit to cost ratio is also used to rank investment option against each other.

4.3.6 STEP 6. Calculation of the properties of increasingly larger cables.

Repeat the calculations in steps 2-5 for available cables as shown in the table below or until the NPV starts to decrease.

Table 15: Summary of all calculations.

Phase conductor size	Cable cost [a] (3 phase plus earth)	Additional cable cost from cost of 16mm² cable	I²R loss of cable (3 phase)	Cost of I²R loss	Saving in cost of I²R loss from cost of 95mm² cable [b]	$NPV_{Savings}$ over 20 years	NPV_{total} over 20 years	Payback period	Benefit to cost Ratio**
		(cc)			*(Y)*	*(NPV)*	*(NPV)*	*(N)*	*(B/C)*
mm²	*$*	*$*	*kW*	*$/yr*	*$/yr*	*$*	*$*	*yr*	
16	355	-	0.207	272	-		-	-	-
25	537	182	0.131	172	100	1,056	874	2.0	4.8
35	708	353	0.094	124	148	1,565	1,212	2.7	3.4
50	**964**	**609**	**0.066**	**87**	**185**	**1,957**	**1,348**	**3.9**	**2.2**
70	1,346	991	0.046	60	212	2,241	1,250	5.9	1.3
95	1,832	1,477	0.033	44	228	2,416	939	8.9	0.6
120	2,301	1,946	0.026	35	237	2,511	565	12.6	0.3
150	2,856	2,501	0.022	28	243	2,578	77	18.8	0.0
185	3,564	3,209	0.017	23	249	2,637	-572	34.4*	-0.2

Source: **AusEng 2015.**

[a] The nonlinear step-like movements in cable cost price are due to how the earth cable size is related to the size of the active cable.
[b] Savings are based on the difference from the 16mm² case (Step 1).
* The investment is not paid back within 20 years.
** Based only on increased cable costs and cost of energy saved.

4.3.7 STEP 7. Selection of economically optimal cable size

All cables with conductor cross sectional areas from 25mm² to 70mm² have a B/C ratio that is greater than unity and their installation would offer lifetime benefits to the owner when compared to the 16mm² cable. The largest positive value of NPV_{total} is $1,348 for the cable with 50 mm² conductor size and therefore is the economically optimal cable size for this example with the assumptions made.

APPENDIX A. PRESENT VALUE (PV_Y)

This section describes a method to evaluate the present value of constant cash flows that is often used in the determination of a capital project's NPV. A typical project involves an initial outlay followed by a series of positive cash flows. Where the series of cash flows are, or assumed to be, constant, the NPV of a typical capital project may be estimated using the following equation:

$$NPV = PV_Y - cc \qquad \text{Equation 15}$$

Where,

cc = all capital costs,

NPV = net present value, and

PV_Y = the present value of the constant cash flows Y.

Note that the PV used in Microsoft Excel requires a detailed knowledge of the PV calculation methodology[20]. Below is a standard finance proof that provides an equation that enables a direct way of calculating the present value.

APPENDIX B. STANDARD FINANCE PROOF OF PV EQUATION

The present value of a cash flow Y_t in t years' time is calculated as follows:

$$PV_{Y_t} = \frac{Y_t}{(1+r)^t} \qquad \text{Equation 16}$$

Where,

PV_Y = the present value of the cash flow,

t = a particular year in the future being discounted,

r = discount rate (expressed as 0.0x (not 1.0x), and

Y = value of a cash flow.

The present value is the sum of the present values of each year's cash flows for the period of time covered:

$$PV_Y = \frac{Y_1}{(1+r)} + \frac{Y_2}{(1+r)^2} + \frac{Y_3}{(1+r)^3} + \cdots \frac{Y_n}{(1+r)^n}$$

Where,

PV_Y = is the net present value of the cash flows representing the savings for the next n years, and

n = a time period expressed as a number of years.

Assuming that each year's cash flows are constant then $Y=Y_1=Y_2=Y_3=\ldots.Y_n$

$$PV_Y = Y\left(\frac{1}{(1+r)} + \frac{1}{(1+r)^2} + \frac{1}{(1+r)^3} + \cdots \frac{1}{(1+r)^n}\right)$$

To simplify this equation substitute x defined as,

$$x = \frac{1}{1+r} \qquad \text{Equation 17}$$

[20] The Microsoft Excel spreadsheet NPV function is not used as it does not directly allow for constant cash flows over a set period of time. The Excel NPV function requires each year's cash flow to be worked out and entered separately into the function, which is unnecessarily time consuming and impractical.

Thus,

$$PV_Y = Y(x + x^2 + x^3 + \cdots x^n)$$

$$PV_Y = Yx(1 + x + x^2 + \cdots x^n)$$

$$\frac{PV_Y}{Yx} = 1 + x + x^2 + \cdots x^{n-1} \qquad \text{Equation 18}$$

Making use of the standard mathematics simplification,

$$x^n - 1 = (x - 1)(x^{n-1} + x^{n-2} + x^{n-3} + \cdots 1) \qquad \text{Equation 19}$$

Equation 19 is only true when n is an integer greater than 0.

Note the last term is $X^0 = 1$

$$\frac{x^n - 1}{x - 1} = x^{n-1} + x^{n-2} + x^{n-3} + \cdots 1 \qquad \text{Equation 20}$$

From Equation 18 and Equation 20 it is apparent that,

$$PV_Y = \frac{Yx(x^n - 1)}{x - 1}$$

Substitute x for r as defined in Equation 17,

$$PV_Y = \frac{Y\frac{1}{1+r}\left(\left(\frac{1}{1+r}\right)^n - 1\right)}{\frac{1}{1+r} - 1}$$

$$PV_Y = \frac{Y\frac{1}{1+r}\left(\left(\frac{1}{1+r}\right)^n - 1\right)}{\frac{1}{1+r} - 1} * \left(\frac{1+r}{1+r}\right)$$

$$PV_Y = \frac{Y\left(\left(\frac{1}{1+r}\right)^n - 1\right)}{1 - (1+r)}$$

$$PV_Y = \frac{Y\left(\left(\frac{1}{1+r}\right)^n - 1\right)}{-r}$$

$$PV_Y = \frac{Y((1+r)^{-n} - 1)}{-r}$$

Multiplying RHS by -1/-1 gives the PV_Y expressed in terms of the three known variables:

$$PV_Y = \frac{Y(1 - (1 + r)^{-n})}{r} \qquad \text{Equation 21}$$

Where,

n = a time period expressed as a number of years,

r = discount rate (expressed as 0.0x (not 1.0x), and

Y = value of a cash flow.

APPENDIX C. PAYBACK EQUATION

This section describes the development of a standard finance equation for calculating the payback period from the NPV formula. The objective is to find the period N where the NPV is equal to zero.

The value of each year's cash in today's value is:

$$NPV = PV_Y - cc \qquad \text{Equation 22}$$

Where,

cc = all capital costs,

NPV = net present value, and

PV_Y = the present value of the constant cash flows Y.

The derivation of PV_Y is given in the document AusEng Fact Sheet FINANCE-Payback Period.pdf, it is defined as,

$$PV_Y = \frac{Y(1-(1+r)^{-n})}{r} \qquad \text{Equation 23}$$

Where,

PV_Y = the present value of the cash flow,

n = a time period expressed as a number of years,

r = discount rate (expressed as 0.0x, not 1.0x), and

Y = a cash flow.

Substituting Equation 23 into Equation 22 gives,

$$NPV = \frac{Y(1-(1+r)^{-n})}{r} - cc \qquad \text{Equation 24}$$

The payback period N corresponds to when the NPV = 0,

$$0 = \frac{Y(1-(1+r)^{-N})}{r} - cc$$

Rearranging

$$\frac{Y(1-(1+r)^{-N})}{r} = cc$$

This becomes

$$(1-(1+r)^{-N}) = \frac{r * cc}{Y}$$

Rearranging

$$(1+r)^{-N} = 1 - \frac{r * cc}{Y}$$

Taking the log of both sides

$$log(1+r)^{-N} = log\left(1 - \frac{r * cc}{Y}\right)$$

$$-N * log(1 + r) = log\left(1 - \frac{r * cc}{Y}\right)$$

$$N = \frac{-log\left(1-\frac{r*cc}{Y}\right)}{log(1+r)}$$ **Equation 25**

Where,

cc = all capital costs ($),

N = payback period (years),

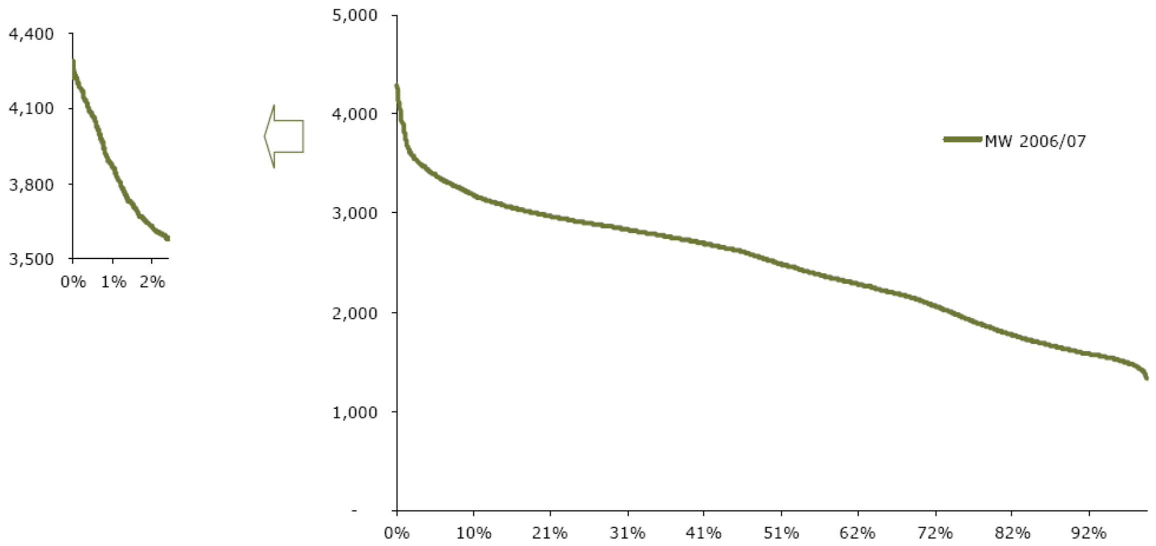
r = discount rate (expressed as 0.0x (not 1.0x), and

Y = value of a cash flow ($).

APPENDIX D. LOAD & PRICE DURATION CURVES

Load duration curves (**Figure 24**) give a sense of overall asset utilisation. Traditionally there are well-defined peak load periods, which at present are growing at a faster rate than base load – this is the present core argument for initiatives such as time of use metering and demand side management through remote control of major appliances (AS/NZS4755). However, as demand side management (either direct control or through pricing) will flatten these curves, the energy demand curves will flatten (**Figure 25**) – the opposite will be true for pricing duration curves such as that shown in **Figure 26** which will probably become more pronounced due to pricing incentives. The South Australian load factors[21] (**Table 16**) indicate approximately 50% loading.

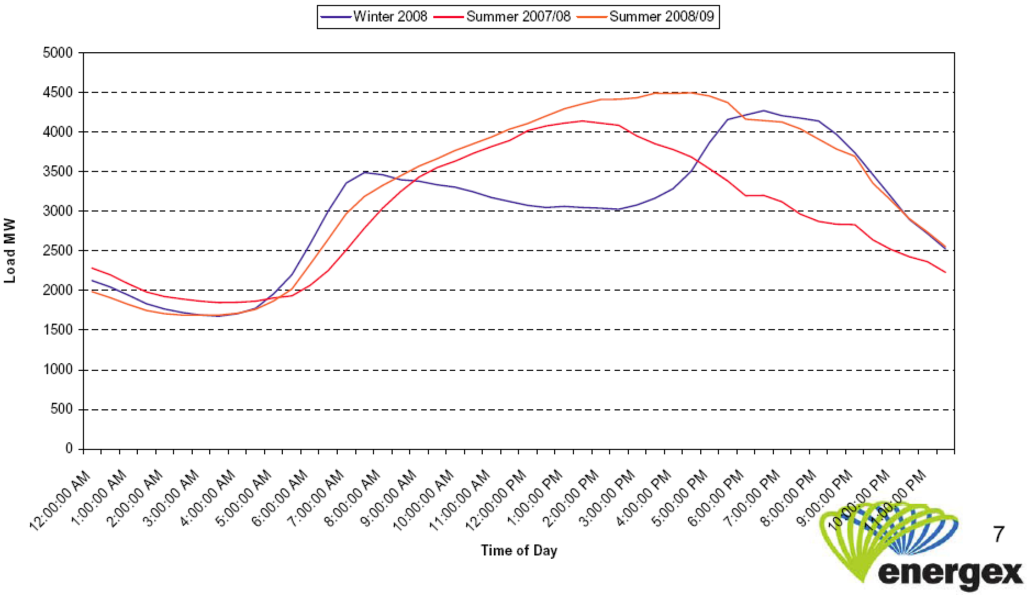
Figure 24: Energex short term peak demand.



Source: Clean Energy Council Energy Efficiency Seminar, Terry McConnell, June 2009.

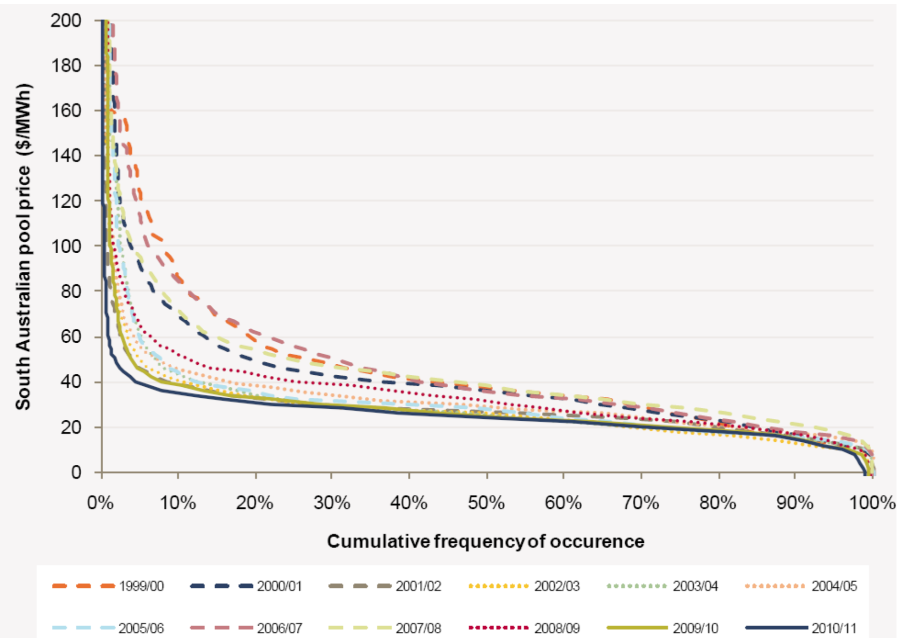
[21] **The load factor is the average load divided by the maximum load in a given time period.**

Figure 25: Energex demand curves – Winter Monday July 2008, Summer Saturday 23 February 2008, Summer 9 Feb 2009.



Source: Clean Energy Council Energy Efficiency Seminar, Terry McConnell, June 2009.

Figure 26: South Australia price duration curves.



Source: South Australian Supply and Demand Outlook – Attachment 4.

Table 16: South Australian load factors.

	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
Load factor	0.53	0.57	0.56	0.52	0.56	0.48	0.50	0.49	0.52

Source: South Australian Supply and Demand Outlook – Attachment 4.