DEEP DIVE CASE STUDY 2:
Heavy Industry Electrical Energy Use and System Design for Energy Efficiency and Sustainability

Companion Guide

Project EEERE:
Energy **E**fficiency **E**ducation **R**esources for **E**ngineering

Consortium Partners:

Queensland University of Technology
The University of Adelaide
Victoria University Melbourne Australia
RMIT University
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La Trobe University Australia

Project Partners:

Engineers Australia
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Project Background

Energy efficiency is widely recognised as the simplest and most cost-effective way to manage rising energy costs and reduce Australia's greenhouse gas emissions. Promoting and implementing energy efficiency measures across multiple sectors requires significant development and advancement of the knowledge and skills base in Australia. Engineering has been specifically identified as a profession with opportunities to make substantial contributions to a clean and energy-efficient future. To further enable skills development in this field, the Department of Industry commissioned a consortium of Australian universities to collaboratively develop four innovative and highly targeted resources on energy efficiency assessments, for use within engineering curricula. This includes:

1. Ten short **'multi-media bite'** videos for each engineering college of Engineers Australia and an introduction (led by Queensland University of Technology with the University of Adelaide);
2. Ten **'flat-pack'** supporting teaching and learning notes (led by University of Adelaide with QUT);
3. Two **'deep-dive case studies'** including worked calculations (led by University of Wollongong); and
4. A '**virtual reality experience'**in an energy efficiency assessment (led by Victoria University).

Specifically, these resources address the graduate attributes of '**identifying**', '**evaluating**' and '**implementing**' energy efficiency opportunities in the workplace, incorporating a range of common and discipline specific, technical and enabling (non-technical) knowledge and skill areas.The four resources were developed with reference to the 2012 Industry Consultation Report and Briefing Note [1] funded by the Australian Government's former Department of Resources, Energy and Tourism (RET), and through further consultation workshops with project partners and industry stakeholders. At these workshops, participants confirmed the need for urgent capacity building in energy efficiency assessments, accompanied by **clear guidance for any resources developed**, to readily incorporate them into existing courses and programs. Industry also confirmed three key graduate attributes of priority focus for these education resources, comprising the ability to: **think in systems**; **communicate between and beyond engineering disciplines**; and **develop a business case** for energy efficiency opportunities.

[1] Desha, C. and Hargroves, K. (2012) *Report on Engineering Education Consultation 2012*, a report and accompanying Briefing Note, Australian Government Department of Resources, Energy and Tourism, Canberra.

Contents

1 Overview

Australia generates about 1.5% of global greenhouse gas emissions. However, on a per capita basis, Australia is one of the world's largest polluters[2]. It is reported that 38% of Australia's total greenhouse gas emissions are a result of electrical energy production and industrial processes[3]. Reduction in electricity use across all sectors, including heavy industry, and an increase in cleaner energy production via renewables, is essential for a timely reduction in global energy related emissions and the promotion of environmental sustainability. Significant reduction in electricity use in industrial plants can be achieved through increased energy efficiency knowledge and implemented measures in electricity distribution and plant design.

This document is the Companion Guide to a *Deep Dive Case Study* analysing energy efficiency in heavy industry, focusing on electricity distribution and utilisation. This *Deep Dive Case Study* focuses on providing knowledge of energy efficiency management strategies and technological options for improving electrical energy utilisation. The case study provides an overview of energy use within a typical industrial plant, allows the student to develop an understanding of the energy loss mechanisms, and enables them to improve their understanding of the impact of design decisions and equipment selection on overall energy efficiency.

This *Deep Dive Case Study* will utilise a whole system approach to analysing a heavy industry plant and electrical distribution system in order to illustrate energy efficiency principals during the design process. The *Deep Dive Case Study* will provide the energy requirements for various mechanical and process loads, identifying how to reduce energy consumption and optimise the design of loads such as motor and lighting systems. It will also illustrate how to use life cycle cost analysis to determine the optimal system component rating and type, under the given design conditions, in order to achieve increased energy efficiency.

2 Benefits you will gain

The case study was developed with three different levels of technical details, knowledge and skills, as illustrated in Figure 2.1. Level 1 focuses on energy use analysis and billing. Based on a base set of typical industrial loads and design conditions, the students can act as an engineering designer to estimate the energy use profile of an industrial plant including components such as lighting, air-conditioning, information technology, plant motors, etc. The students can also evaluate the impact of modifying time of use of equipment and understand the impact on overall energy use and peak load. This level allows for discussion on matching load to generation, including the impact of localised renewable generation, and the cost impact based on flat rate, time of use, or demand based energy charges.

Level 2 mainly focuses on the energy efficiency and life cycle costs associated with the design of the electrical supply system. This includes transformer selection, cable sizing and loss calculation, and lighting and motor type selection. Level 3 focuses on the estimation of energy savings, and impact on operating cost, for the application of a variable speed drive to a simple pumping system with variable flow rate requirements. Level 2 and Level 3 use a problem-based learning approach to highlighting engineering considerations in the design of electrical and pumping systems and selection of equipment technologies.

[2] http://www.carbonneutral.com.au/climate-change/australian-emissions.html, accessed 10th December 2013
[3] Commonwealth of Australia, Quarterly Update of Australia's National Greenhouse Gas Inventory: March 2014, Department of Environment, http://www.environment.gov.au

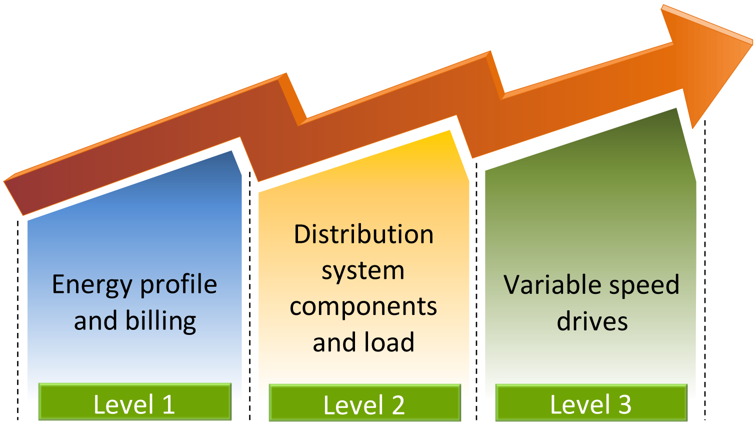


Figure 2.1 - Illustration of the three-level deep dive case study

Through utilising the case study at various levels you will develop a holistic understanding of the impact of various design decisions on heavy industry plant component energy use and gain knowledge of electrical distribution system and equipment design principles in general.

3 The case study task

You are to assume the role of a process or electrical design engineer. By analysing the scenarios available to you in the case study software, you are to evaluate the design options put to you in the design brief (Section 3.1) and provide suitable justification for your selected set of design parameters.

A range of scenarios below can be covered and tested in this case study in relation to heavy industry:

- Selection of plant loads and technologies to be included in plant energy profile including consideration of technologies to improve energy use at load/process.
- Electrical distribution design scenarios: meeting process and mechanical load requirements, layout design criteria for energy efficiency.
- Selection of individual electrical equipment components for energy efficiency: cable design; transformer design; lighting selection; and motor selection using whole system approach.
- Estimation of energy use based on system design, operational scenarios, loss mechanisms, and equipment selection; optimisation of design based on energy use.
- Variable speed drive application and calculation of energy savings; dependency on voltage control, load cycle and load type.
- Use life-cycle cost analysis and design considerations to determine optimal variable speed drive design: equipment cost, installation and operational cost, lifecycle and energy savings.

The background details (assumptions, methodology and calculations) of each level of the case study software (refer to Figure 2.1) can be found in Section 4 to Section 6.

3.1 The design brief

As a process or electrical design engineer you are charged with the design and analysis of designing a plant using standard components and loads, e.g. distribution system components based on required rating, standard motor and lighting technology, etc. As a design engineer you also are to complete the design of the same plant utilising high efficiency components and loads and design methodologies aligning with energy efficient practises. You are to complete a full life cycle analysis of cost of ownership of each plant design, establish energy requirements and quantify emissions. You are to complete the activities outlined below related to the design of the plants. Assistance in defining the detailed scope of the task related to the two plant designs will be provided through workshop discussion.

3.1.1 Plant energy demand profile

By selecting all relevant loads and establishing their time of use, or duty cycle, develop a demand profile for each equipment type and establish the total plant demand. Analyse how the plant demand can be manipulated by altering processes in order to produce different plant profiles. By applying the available billing system options, determine which plant profile provides the least cost option for each billing type.

3.1.2 Design of plant electrical distribution system and load

For the plant equipment established in Level 1 spreadsheet, design a suitably rated electrical distribution system based on required ratings only. Establish the energy profile using standing equipment, e.g. use the least efficient motor and lighting systems. Determine an alternative design by selecting more energy efficient equipment technologies for motor and lighting, also utilise a more efficient power system transformer and optimise cable sizing for energy efficiency. Quantify the difference in up front, operational and life cycle costs of the more efficient plant.

3.1.3 Variable speed drive for plant pumping system

Given that a number of the motor systems in a heavy industrial plant will be related to pumping, assign a number of the motors in your demand profile from Level 2 spreadsheet to be considered for variable speed drive applications. Assume that the assigned pumps are throttle controlled in the low efficiency plant design. Establish the life cycle cost benefit of making those throttle controlled pumping systems variable speed drive applications.

3.2 Task outcomes

On completing this task, you will have gained knowledge on energy usage analysis and energy efficient electrical design constraints for heavy industry plants, and established the impact of various energy efficiency design principles in general.

In the area of plant energy use analysis the key learning activities are as follows:

- Understand how each load contributes to create the total demand curve and how control of loads can bring down the peak demand value;
- Understand the effects of a range of variables and equipment selection options (e.g. ratings, system losses, duty cycle and time of use, etc.) on plant energy use; and
- Understand how to optimise the electrical distribution system design in order to reduce energy consumption and energy costs (including application of different tariff schemes);

Energy efficient Electrical Design:

- Understand the effects of a range of variables (e.g. duty cycle, peak demand) have on the design and selection of electrical distribution system components;
- Understand how to determine economic factors such as net present value and return on investment for justification of energy efficiency projects;
- Understand how to appropriately selection power system components, e.g. transformer and cabling, in order to optimise design for energy efficiency and reduced life cycle costs; and

- Compare the performance of lighting and electrical motor system under different design options and energy efficiency retrofit applications.

In the area of variable speed drive design, the key learning activities are as follows:

- Understand the effects of a range of variables (e.g. motor rating, process flow requirements, motor speed) on energy losses in a flow control process;
- Understand how to appropriately size pumping system components based on given design flow rate and system pressure drop calculations;
- Understand how to optimise control methods for energy efficiency;
- Compare energy losses of electronic variable speed drive controlled systems with valve controlled pumping systems; and
- Understand how variable speed drive applications enable energy efficiency improvements.

3.3 Task outputs

The deliverable output of this task is to be a summary report (limited to six pages) which details the considerations and design options outlined in the design brief. Specific outputs generated from case study calculations are to be included in the report to justify design parameter selections and/or verify impact of design alternatives (where applicable). Discussion and/or recommendations for optimal plant component and equipment design with respect to the low and high efficiency plant are to be included in the summary report. Include any external factors (beyond the case study software options) which you think would be important in regards to minimising plant energy use.

Where activities are undertaken in a group, the summary report must indicate the contributions from each member. Presentation of results will be required during tutorial discussion.

4 Energy usage analysis

This section is focused on providing knowledge on how each load of a heavy industrial plant impacts on the overall electrical energy demand, how it contributes to the total annual energy usage, and how the time of operation impacts on plant peak demand. Users can study various demand curves related to the different types of loads and compare to the total demand curve. Also, this section provides an understanding of how the total demand curve changes when the usage percentage values (time of use and duty cycle) change during a day. Furthermore, in this section the user can understand how different types of tariff schemes work and establish their selection impacts on overall operational costs.

The following default loads, listed below, are considered for the initial calculations. The user can manipulate all these load types and provide additional loads where required. The ranges of equipment loads are not limited but may be introduced as part of the Deep Dive Case Study task.

- Lighting Loads 50 kVA
- HVAC loads 50 kVA
- Lifts 20 kVA
- Computer Loads 75 kVA
- Other Loads 50 kVA
- Motor loads 20, 2.2 kW

The power factor is assumed as 0.85 lagging for the non-resistive loads. The user can change the load values and the usage percentages as desired. These values are reused in the next spreadsheet.

4.1 How to use the software

Step 1: The user can click "Calculate" to see the daily total electricity demand and the total cost per day utilising the default values assigned to each load type.

Step 2: The use can modify the ratings of each load type and the load profile by entering or modifying data in each of the spreadsheet columns.

Step 3: User can click "Demand Curves" to compare the hourly demand curves related to each load and the how total demand curve varies during a particular day.

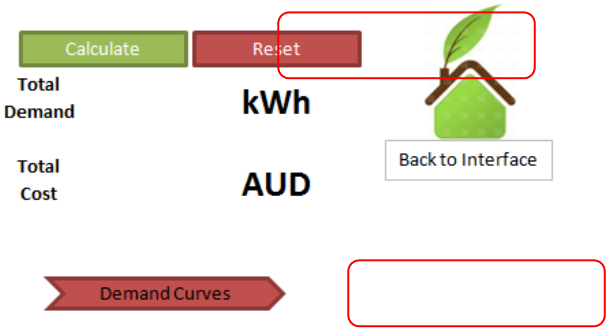


Figure 4.1 - Software user interface

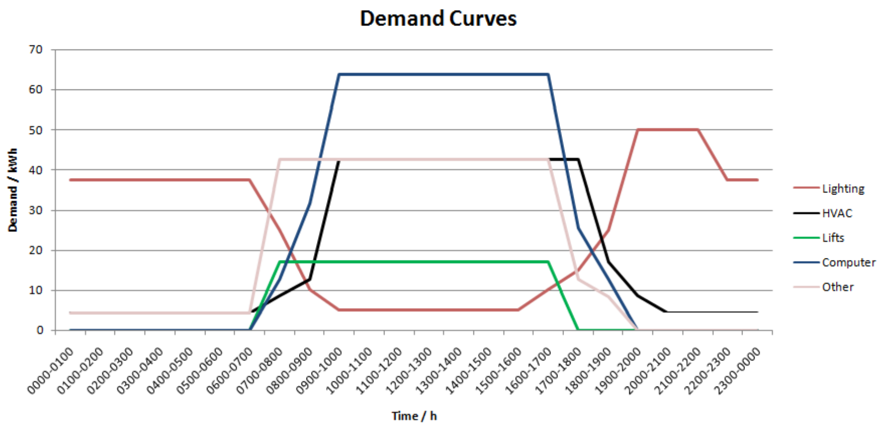


Figure 4.2 – Example individual load type demand curves

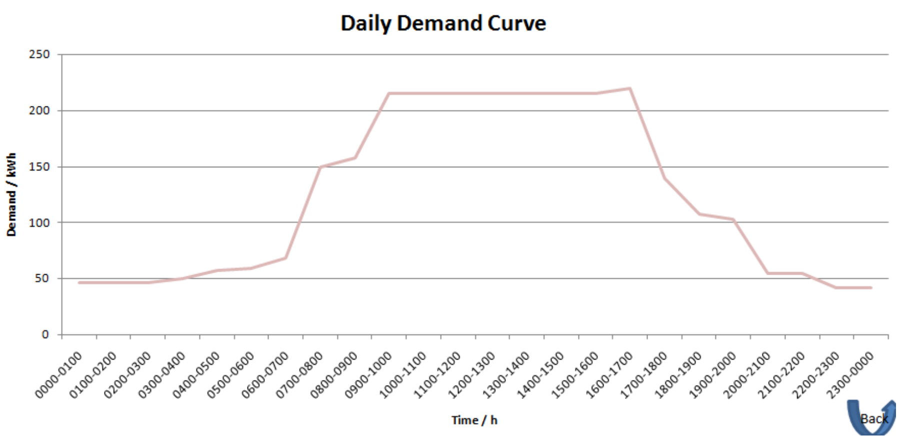


Figure 4.3 – Example total plant demand curve

Examples of the graphical output for the individual hourly energy load profiles and total hourly energy demand curve are illustrated in Figure 4.2 and Figure 4.3.

Step 4: The user can change the tariff category from the drop down list provided by selecting “Flat rate”, “Time-of-use” or “Demand” and then analyse how the total cost changed according to the tariff scheme (refer Figure 4.4).

For the “Flat rate” tariff scheme it is assumed that the energy price = $ 0.21 /kWh

For the “Time-of-use” tariff scheme it is assumed that the energy price for peak time (11:00 am – 10:00 pm) = $ 0.42 /kWh, and for other times = $ 0.21 /kWh

For the “Demand” tariff scheme it is assumed that for the peak demand, i.e. the daily peak demand, the additional cost of $ 9.00 is charged per kWh. For example, if the peak demand is 220 kWh and the total demand for the day is 2950 kWh,

Total = (2950 X 0.21) + (220 X 9)

d	Tariff	
	Demand	Charges
46	Flat rate Time-of-use	9.66
46	Demand	9.66
46	0.21	9.66
).4	0.21	10.584
57	0.21	11.97
).2	0.21	12.432

Figure 4.4 – Changing energy billing tariff scheme

Step 5: As the second stage of the Level 1, the user can change the usage percentages of each load and observe the changes of total demand curve and the total energy cost following the implementation of Steps 1 to Step 4.

Hours	Lighting	HVAC	Lifts	Computer Loads	Other Loads	Motor Loads	Total Demand	Tariff	
	50	50	20	75	50	44		Demand	Char
0000-0100	75	10	0	0	10	0	46	0.21	
0100-0200	75	10	0	0	10	0	46	0.21	
0200-0300	75	10	0	0	10	0	46	0.21	
0300-0400	75	10	0	0	10	10	50.4	0.21	
0400-0500	75	10	0	0	10	25	57	0.21	
0500-0600	75	10	0	0	10	30	59.2	0.21	
0600-0700	75	10	0	0	10	50	68	0.21	
0700-0800	50	20	100	20	100	100	149.75	0.21	3
0800-0900	20	30	100	50	100	100	158.125	0.21	33

Figure 4.5 – Changing load type demand profiles

5 Energy efficient electrical design

In the Level 2 spreadsheet of the software, the user can gain knowledge on incorporating energy efficiency criteria into the design and selection of the major components of a heavy industry electrical distribution system. For this task, the theory of life cycle costing is used to identify the present values of the savings from the components of the system. Transformer, cables, lighting types and motors are considered as the default major components in the system. For each major component, detailed analysis is provided to assist the user in selection the optimal energy efficient components.

Data from the Level 1 (energy usage analysis) is used as the default values for this level but may be altered as required to suit activities.

5.1 Transformer selection

For the energy efficient electrical design (Level 2) spreadsheet within the software the user can select a suitable rating for the distribution transformer based on system load, standard sizing or by optimising for energy efficiency. The desired loading of the distribution transformer is selected, a percentage value can be entered, and by clicking “Calculate” the total load data from the Level 1 spreadsheet is imported into the Level 2 spreadsheet and displayed accordingly. Refer to Figure 5.1. Then, by comparing with total load, the user can select an appropriate transformer rating (in kVA) from a drop down list.

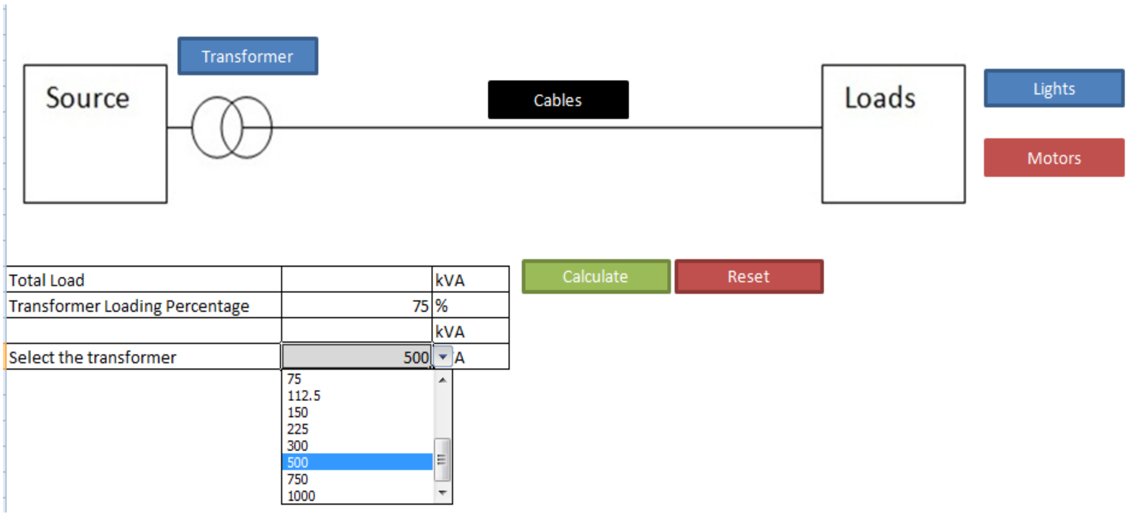


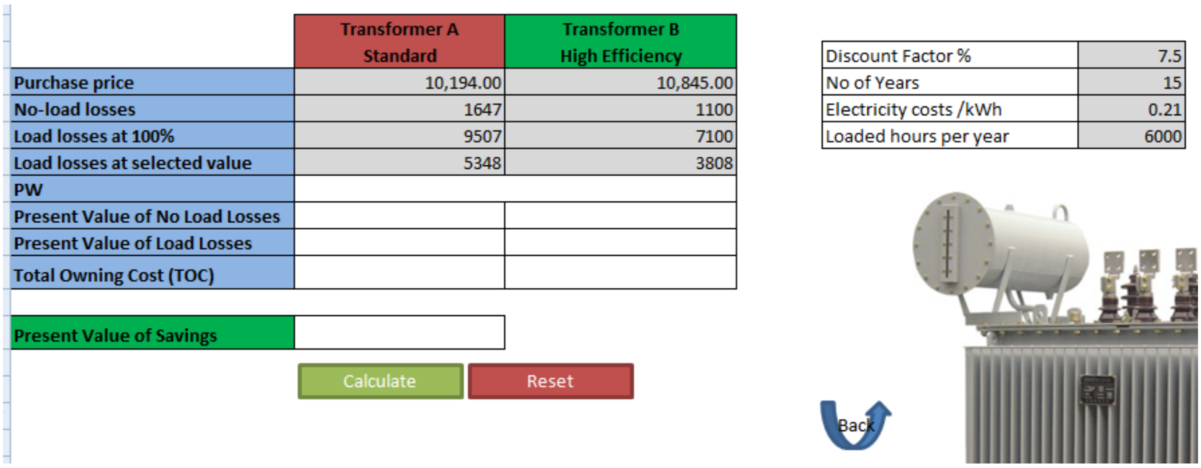
Figure 5.1 – Interfacing for Level 2 software platform

5.1.1 Transformer selection for energy efficiency

In this analysis, a standard transformer and a high efficient transformer are compared with their purchase value, load and no-load losses and derived values for the total owning costs and the relevant savings.

Step 1: Click “Calculate” to see the savings values.

Step 2: Change the loaded hours per year, life cycle of transformer (i.e. number of years), and determine how the transformer losses and total owning cost change for various scenarios.



	Transformer A Standard	Transformer B High Efficiency
Purchase price	10,194.00	10,845.00
No-load losses	1647	1100
Load losses at 100%	9507	7100
Load losses at selected value	5348	3808
PW		
Present Value of No Load Losses		
Present Value of Load Losses		
Total Owning Cost (TOC)		
Present Value of Savings		

Discount Factor %	7.5
No of Years	15
Electricity costs /kWh	0.21
Loaded hours per year	6000

Figure 5.2 – Interface for transformer comparison

5.1.2 Calculations for transformer selection

The following outlines the calculations embedded into the Level 2 spreadsheet for estimation of costs and losses associated with transformer selection.

Total Owning Cost (TOC) = Purchase price
+ Present value of future no load losses
+ Present value of future load losses

No load losses per year = Transformer no load losses
x 8760 h/year
x Electricity cost/kWh
x PW

Load losses per year = Transformer load losses
x Loaded hours per year
x Electricity cost/kWh
x PW

Where,

$$PW = \frac{(1+i)^n - 1}{i\,(1+i)^n}$$

And, n = number of years (life cycle or project years), and i = discount factor.

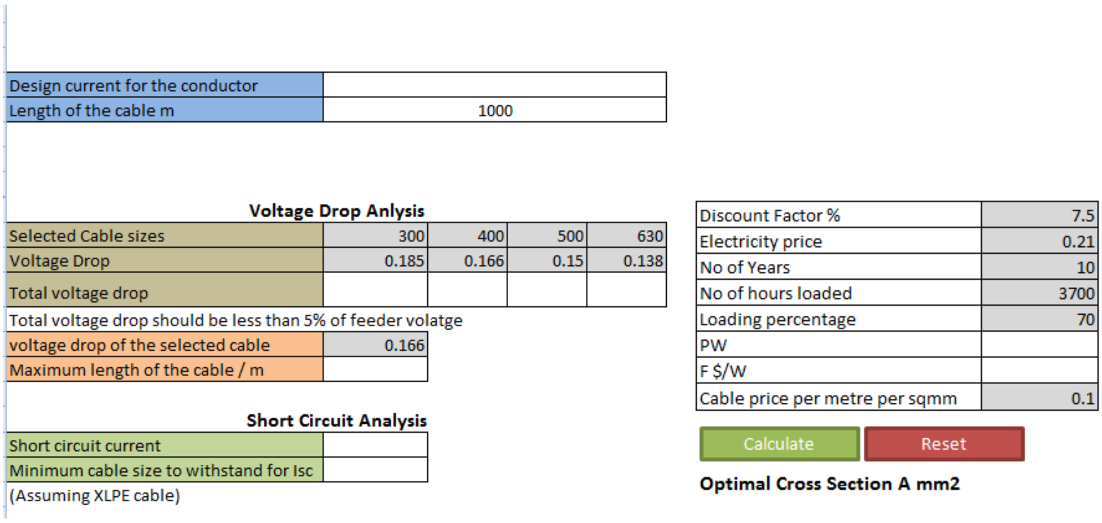
5.2 Cable selection

Here, cable selection is focused on the cable from the transformer to the loads (e.g. emulating supply to and from the plant's main switch board). Design current is calculated based on the total load value of the Level 1. An optimal cable size is calculated given financial and electrical factors. This analysis covers the areas of voltage drop, short circuit current, and a cable comparison which is based on the loss cost and total cost per metre of cable.

5.2.1 Cable selection for energy efficiency

In this analysis, a design using standard cable sizing and a design considering energy efficiency parameters are completed.

Step 1: User can click "Calculate" to observe the value for "Optimal Cross Section" and selected cables accordingly for the cable comparisons with their voltage drop values.



Design current for the conductor	
Length of the cable m	1000

Voltage Drop Anlysis

Selected Cable sizes	300	400	500	630
Voltage Drop	0.185	0.166	0.15	0.138
Total voltage drop				

Total voltage drop should be less than 5% of feeder volatge

voltage drop of the selected cable	0.166
Maximum length of the cable / m	

Short Circuit Analysis

Short circuit current	
Minimum cable size to withstand for Isc	

(Assuming XLPE cable)

Discount Factor %	7.5
Electricity price	0.21
No of Years	10
No of hours loaded	3700
Loading percentage	70
PW	
F $/W	
Cable price per metre per sqmm	0.1

Calculate Reset

Optimal Cross Section A mm2

Figure 5.3 – Cable selection interface

Step 2: Observe the graph and see how lost cost and total cost of cables (per m) varies and select a suitable conductor size.

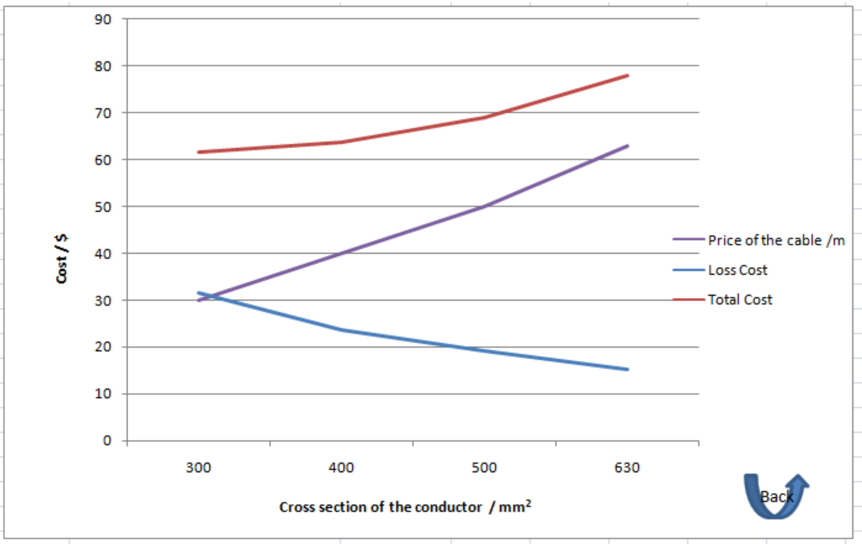


Figure 5.4 – Cable cost variations

Optimal cable selection should be based on the lowest total cost where the red curve is a minimum. But in this case we have to use a cable which is larger than 300 mm^2 (cross sectional area). Therefore, optimal cable is 400 mm^2 for the parameters shown, i.e. needs to be larger.

Step 3: Insert the voltage drop value for the selected cable to see what the maximum cable length that can be used to maintain the voltage drop value.

5.2.2 Calculations for cable selection

The following outlines the calculations embedded into the Level 2 spreadsheet for estimation of costs and losses associated with cable selection.

Cross sectional area of cable, *A*

$$A = I_r \times 0.1433 \times \left(\frac{F}{C_c}\right)^2$$

Where, I_r = Rated current in the circuit
C_c = Cable price per meter and per mm^2 cross section

$$F = (P_{loading})^2 \times t_{hours} \times T_{tariff} \times PW$$

Where, $P_{loading}$ = Cable load value, i.e. 75% = 0.75
t_{hours} = Number of hours cable loaded
T_{tariff} = Electricity cost ($/kWh)

Total cost of cable per meter length

$$C_T = (C_I + C_L)$$

$$C_T = (C_c \times A) + \left(\frac{1}{A} \times I_r^2 \times 0.02054 \times F\right)$$

Where, C_I = Cable investment cost
C_L = Cable loss cost

5.3 Lighting selection

In this section, selection of lights is based on two different scenarios. First one is the new design which is derived from the basic parameters and is calculated the no of fixtures required from each different lamps. The second one is aimed towards a retrofit design where the number of fixtures is constant. In the retrofit design, lux levels before and after the retrofit is compared.

5.3.1 Lighting selection for energy efficiency

In this analysis, a design using various types of lighting technologies is considered in order to improve energy efficiency.

Step 1: Click “Calculate” to see the number of required fixtures required relevant to each lamp type for the design, energy cost per year for each type of luminaire. The user can change default data according to their designs.

Lighting Layout Calculator

Area to be lit/ m2	150
Desired Lux level	265
Average number of hours on per year	3000

	Luminar 1	Luminar 2
Watts per fixture	18	20
Number of lamps per fixture	2	2
Rated mean lumen per lamp	500	700
Ballast factor (BF)	1	1
Coefficient of Utilization (CU)	0.6	0.6

Electric cost per kilowatt hour AUD	0.21

No of fixtures required		
Total power load kW		
Energy cost per year		

Calculate

Reset

Figure 5.5 – Lighting design interface

Step 2: Click “Consider a Retrofit Situation” to go to retrofit design. Click “Calculate” and check whether desired lux level can be achieved with new luminaire. The user can analyse the graph how lux level is changed due to the retrofit.

Area/ m2	150
Average number of hours on per year	3000

Compare Life Cycle Cost

	Luminar 1(New)	Luminar 2(Existing)
No of Fixtures	47	
Watts per fixture	18	20
Number of lamps per fixture	2	2
Rated mean lumen per lamp	500	700
Ballast factor (BF)	1	1
Coefficient of Utilization (CU)	0.6	0.6
Operating Cost Per Year		

Calculate Reset

Existing Lux Level with existing luminar	
Achieved Lux Level with new Luminar	

Figure 5.6 – Lighting retrofit design interface

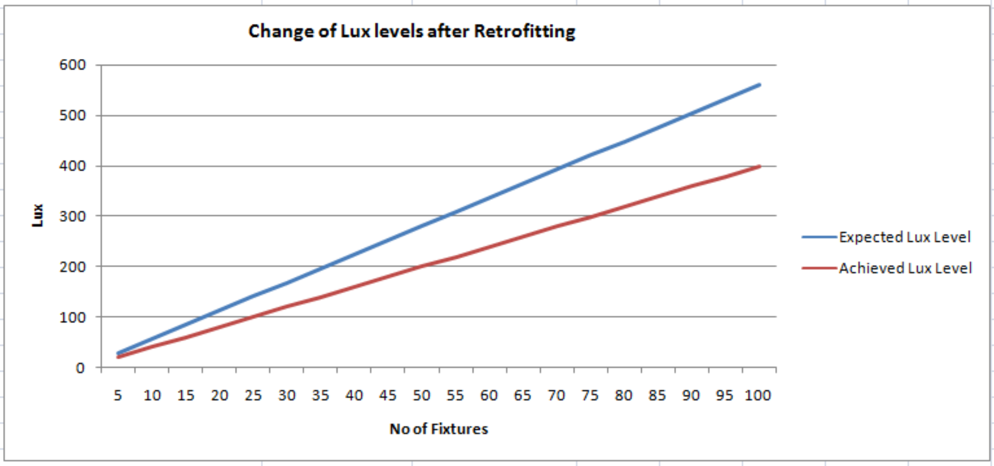


Figure 5.7 – Lux level variation with different luminaire

According to the graphs illustrated in Figure 5.7, even though the new luminaire saves operating costs, achievable lux level drops. Understanding the impact of energy efficiency measures on process output, in this case light, is vital if projects are to be realised effectively.

5.3.2 Calculations for luminaire selection

The following outlines the calculations embedded into the Level 2 spreadsheet for estimation of lux output, cost and losses associated with luminaire selection.

$$No\ of\ Fixtures = \frac{Area \times Desired\ Lux\ level}{No\ of\ Lamps\ per\ fixture \times Rated\ mean\ lumes\ per\ lamp \times BF \times CU}$$

Where, CU = Coefficient of utilization

BF = Ballast factor

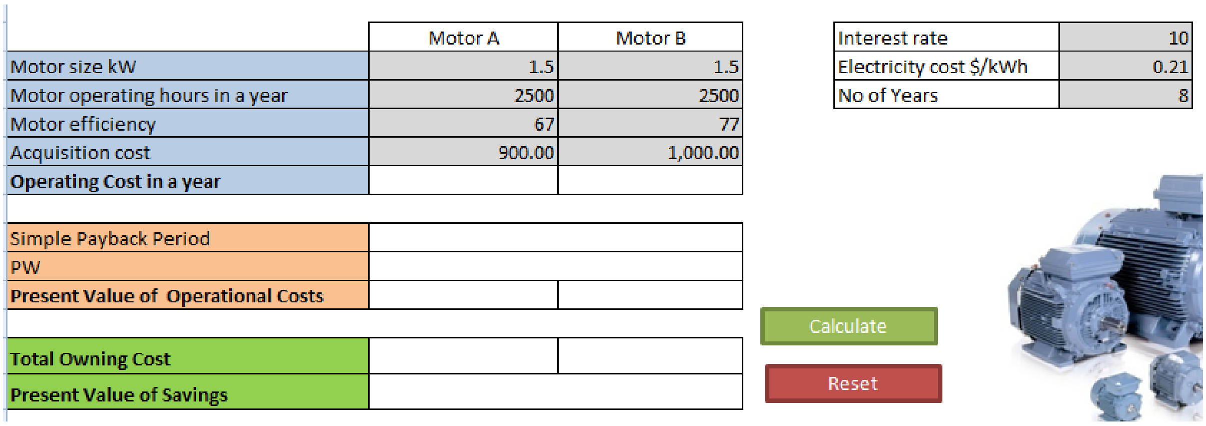
5.4 Motor selection

This analysis is based on the total owning costs of a low efficient motor and a high efficient motor. In this section, user can identify the variations of motor operating costs with the motor efficiency and the total cost variations with the years.

5.4.1 Motor selection for energy efficiency

In this analysis, a design using various types of motor efficiencies is considered in order to improve overall plant energy efficiency.

Step 1: User can click “Calculate” to compare total owning costs, simple payback periods and operating costs of motors with different efficiencies. User can change the efficiency values and related motor cost to see how total owning cost changes.



	Motor A	Motor B
Motor size kW	1.5	1.5
Motor operating hours in a year	2500	2500
Motor efficiency	67	77
Acquisition cost	900.00	1,000.00
Operating Cost in a year		
Simple Payback Period		
PW		
Present Value of Operational Costs		
Total Owning Cost		
Present Value of Savings		

Interest rate	10
Electricity cost $/kWh	0.21
No of Years	8

Figure 5.8 – Motor comparison interface

Step 2: Observe the generated graphs. Following graph, Figure 5.9, shows how motor operating cost varies with the motor efficiency.

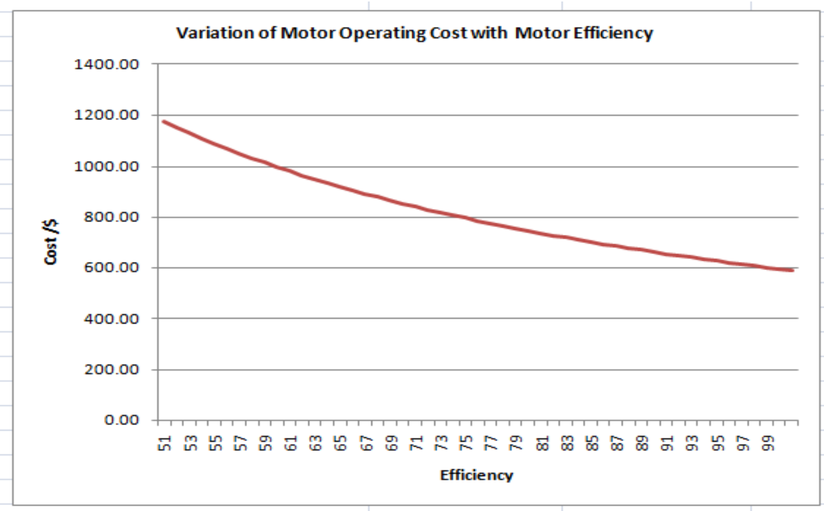


Figure 5.9 – Motor operating cost variation with efficiency

The next graph, Figure 5.10, provides an idea of how total costs of two motors with different efficiencies vary. Also, it shows how the total saving (if Motor B is used) increases with the years.

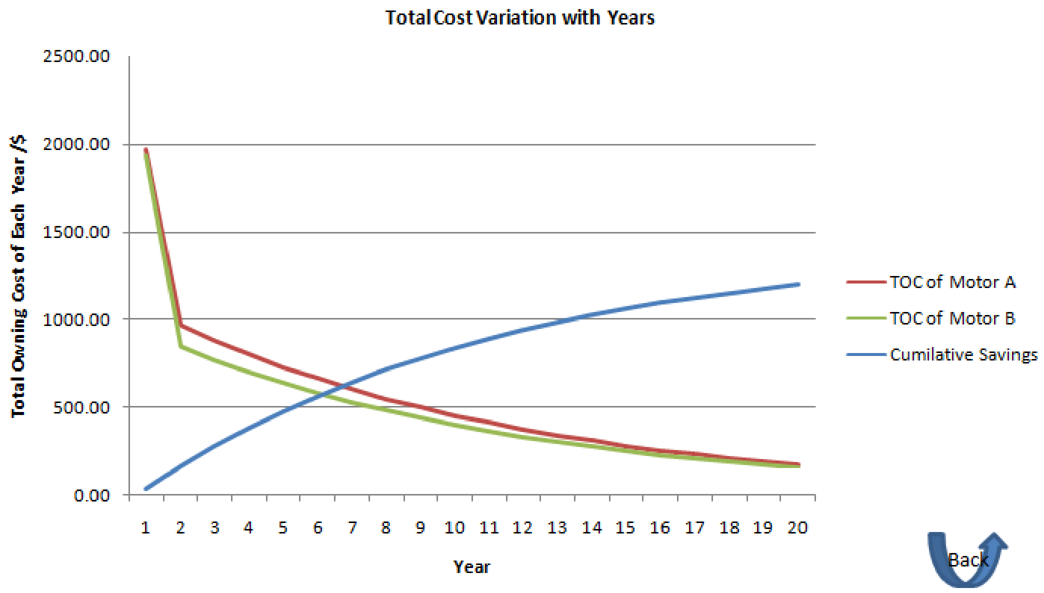


Figure 5.10 – Total cost variation with years for different efficient motors

5.4.2 Calculations for motor selection

The following outlines the calculations embedded into the Level 2 spreadsheet for estimation of motor operating cost and losses associated with motor selection.

$$Motor\ Operating\ Cost(MOC) = \frac{Motor\ operating\ hours\ \times\ Motor\ kW\ rating\ \times\ Electricity\ cost}{Motor\ efficiency}$$

Total Owning Cost = Motor acquisition cost + (Motor Operating Cost x PW)

6 Variable speed drive systems

In Level 3 of the *Deep Dive Case Study* software a variable speed drive system is considered. In this case it is used to drive a pumping system. The motor capacity is set at default value of 15.1 kW with an efficiency of 92%. This systems pumps water to a 32 m head with a flow rate of 125 m^3/h. The flow rate required for the example process is not constant throughout the day. It can be reduced by 25% of its initial value. If a throttle valve is used to adjust the flow rate, the motor runs with its full capacity, whereas a VSD system can reduce the motor speed in order to achieve the required flow rate.

This scenario is analysed to come up with values for energy savings when the VSD system is used.

6.1.1 Variable speed drives for energy efficiency

In this analysis, a design using variable speed drives for a pumping application is analysed in order to quantify the improvement in overall plant energy efficiency.

Step 1: The user can click “Calculate” to see the values of associated electricity cost of two different systems. Observation of the power consumption variations due to flow rate change by VSD system and a normal throttling valve system are reported via graphical means and in tabulated form.

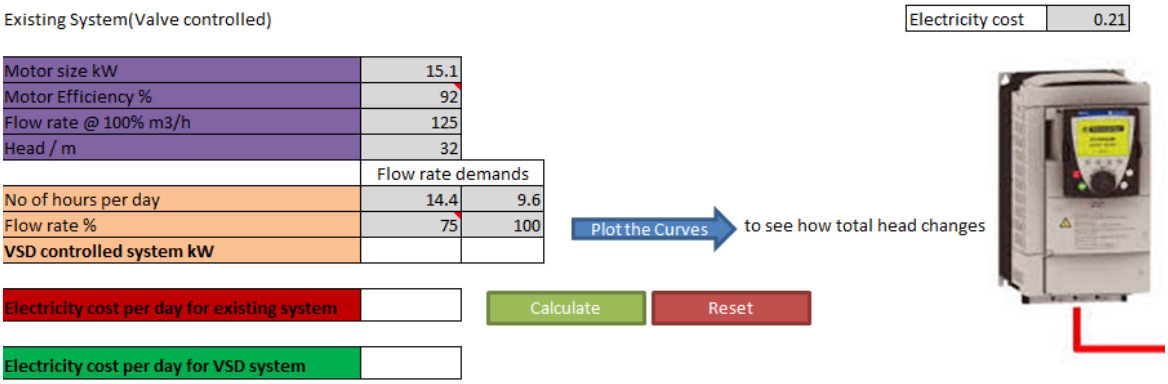


Figure 6.1 – Level 3 Variable Speed Drive Interface

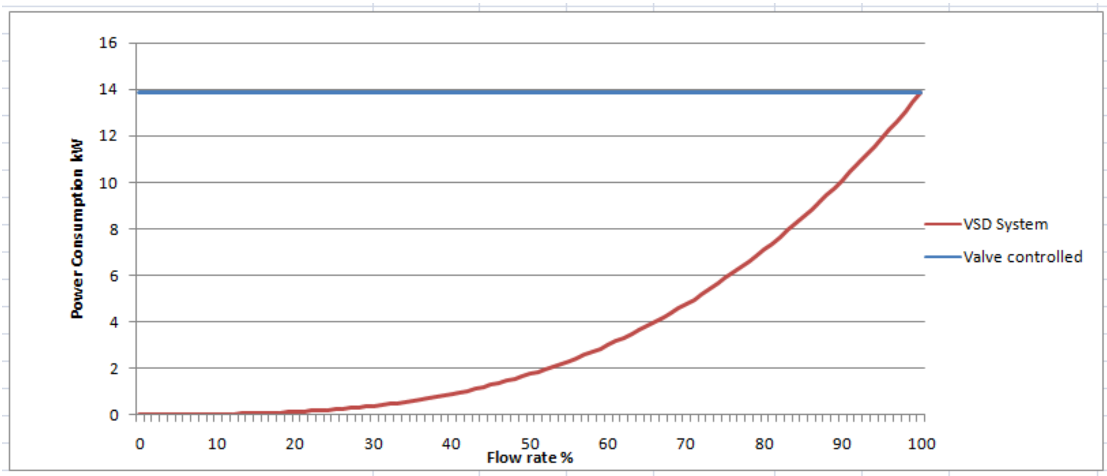


Figure 6.2 – Power consumption variation for two VSD and valve controlled systems

Step 2: Click "Plot the curves" to observe the variation of pump head when flow rate is changed by controlling speed using VSD.

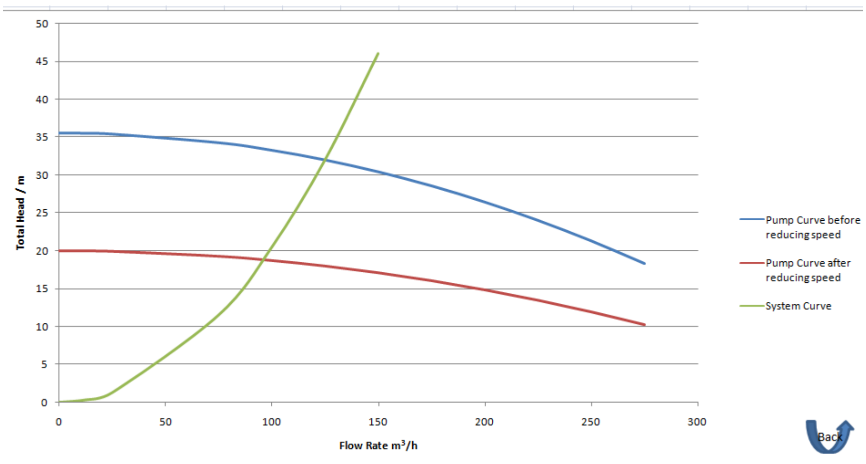


Figure 6.3 – Curve illustrating variation of pump performance

In this case, the pump curve changes due to the speed change from the VSD system. Initially, the pump has a flow rate of 125 m^3/h, while maintaining a 32 m head. However, due to the specific need of a 25% reduced flow rate, the VSD system changes the flow rate to a reduced value.

Step 3: The user can change the reduced flow rate value to a different value and see the variation by following the above step.

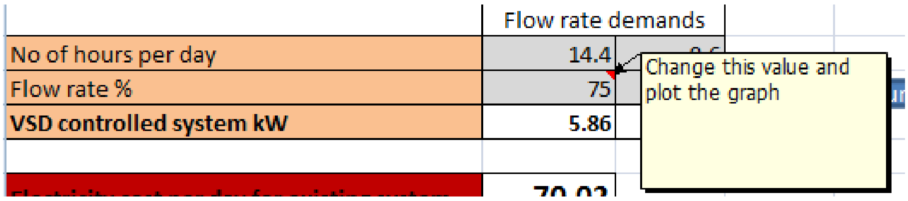


Figure 6.4 – Changing flow rate interface

6.1.2 Calculations for variable speed drive application

The following outlines the calculations embedded into the Level 3 spreadsheet for estimation of energy savings and energy efficiency associated with variable speed drive implementation.

Affinity laws used,

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \qquad \frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

Where, Q = Volumetric flow (m^3/s)
H = Head (m)
P = Power (W)
N = Speed (rpm)