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

Supporting Material

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
University of Wollongong
La Trobe University Australia

Project Partners:

Engineers Australia
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Australasian Association for Engineering Education
energy efficiency council
asbec Australian Sustainable Built Environment Council

Australian Government
Department of Industry

Citation Details

H.P.A.P. Jayawardana, D. Robinson, (2014) *Deep Dive Case Study: Heavy Industry Electrical Energy Use and System Design for Energy Efficiency and Sustainability - Supporting Material*, a guide produced by University of Wollongong for the Energy Efficiency Education Resources for Engineering (EEERE) Project, led by the Queensland University of Technology. An initiative of the Australian Government's Department of Industry, Canberra.

Acknowledgements

The consortium thanks the 40 workshop participants (Brisbane, Sydney and Melbourne) including stakeholder partners, college members, industry and academic colleagues, who provided their time and ideas so generously during the stakeholder engagement parts of the project, and to those who have assisted in reviewing the drafted resources. The consortium thanks our project partners for their continued commitment to building capacity in delivering sustainable solutions, the federal government for funding the initiative, and the following individuals for their ongoing support of capacity building in engineering education: Mr Stuart Richardson, Mr Luiz Ribeiro, Ms Denise Caddy and Mr Nick Jackson. The authors acknowledge the invaluable inputs made by Dr Cheryl Desha of Queensland University of Technology for her inputs into this case study and leadership of the consortium of academics participating in the Energy Efficiency Education Resources for Engineering (EEERE) project.

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 Introduction

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 outlines a *Deep Dive Case Study* analysing energy efficiency in electricity distribution and utilisation in heavy industry. Based on provided or selected power system and load parameters (rating, type, time of use, etc.), the case study looks at energy use, electricity billing, distribution system equipment design, variable speed drive implementation, and the subsequent impact on energy efficiency. While the latter of these technologies are specific to electricity utilisation, the approach of the case study attempts to remain holistic to establish the impact of specific design decisions on the overall energy use, and subsequently, energy efficiency in the broader sense as an engineering challenge.

This deep dive case study will demonstrate how to analyse industrial plant energy use to identify possible technical options to reduce energy consumption, optimise the design of the electricity distribution systems and implement variable speed drives for water pumping systems. It will illustrate how to determine the optimal electrical system components (conductor, lighting type, variable speed drives, etc.) in order to achieve energy efficiency.

This document provides an overview and objectives for engineering faculties, addressing:

- Graduate attributes and learning outcomes (both technical and enabling) to be developed through using this resource.
- Potential learning pathways for developing the identified knowledge and skills.
- How the learning outcomes link to Engineers Australia accreditation requirements and Stage 1 competencies.
- How the learning outcomes link to other high order competencies, such as improvements in graduates' abilities to conceptualise energy efficiency issues, and to work in multi-disciplinary teams to assess and implement energy efficiency opportunities (e.g. with accountants etc.).
- How the resources and the learning outcomes will produce graduates that are more job-ready in relation to energy efficiency assessment, management, monitoring, project analysis and implementation.
- The engineering sub-disciplines for which the resources are relevant.

The document also provides information regarding guidance documents or advice for lecturers to:

- Provide practical guidance or advice to lecturers and faculties wishing to incorporate the resources, and
- Support lecturers' practical understanding of energy efficiency in an industrial context, and their capacity to teach it effectively.

[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

2 Statement of coverage

2.1 Resource focus

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.

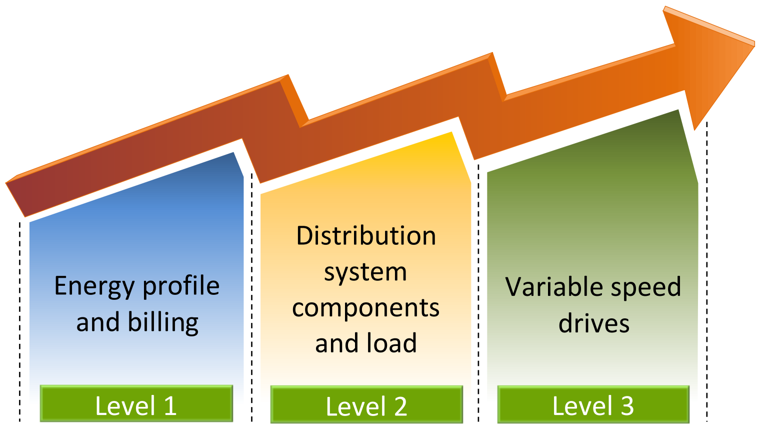

Figure 2.1 - Illustration of the three-level deep dive case study

The *Deep Dive Case Study* simulation and software platform utilises Microsoft Office Excel (2010 and above) and Visual Basic Application. The software platform is provided "unlocked" to ensure educators and students can investigate all aspects of calculation and simulation. Tasks can also be based on expanding or modify the spreadsheet calculations and methodology. The Microsoft Excel platform is utilised to enable the case study to be expanded through the creation of additional themes or entirely new case studies, e.g.:

- Integration of different load types in order to determine overall demand curves and impact on energy efficiency and operating costs;
- Adjusting the load types for the variable speed drive to analyse the potential energy savings achieved for each type; and
- Expanding the capabilities of the spreadsheet to integrate other energy efficiency options such as voltage conservation, etc.

Level 1 of the *Deep Dive Case Study* software is a single level worksheet and provides a general understanding of the impacts of load operation on plant energy usage profile including cost based on billing structure, impact on maximum demand and time of use schedules. The software is able to run simulation according to user defined inputs and provide results graphically in terms of total individual equipment and total plant energy demand profile. This part of the software is also designed to calculate total electrical energy and billing costs based on the design conditions which are subsequently used in the Level 2 spreadsheet, i.e. electrical system design.

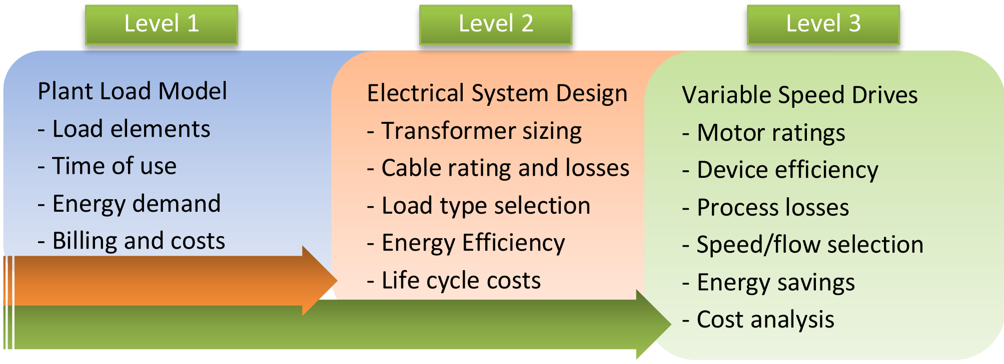

Figure 2.2 - Illustration of the three-level deep dive case study

Level 2 of the software enables the user to design and optimise the electrical distribution system components and load types for the *Deep Dive Case Study*. Transformer rating and efficiency can be altered to enable the user to understand the impact of losses and cost of ownership over the lifespan of the equipment. Cable system design and optimisation including consideration for energy losses and cost of ownership are determined based on user inputs and requirements based on standards. Selection of lighting based on output lux level, device selection and quantity, or comparison with retrofit of more energy efficient types is able to be analysed. User can also modify the parameters for motor load selection to assist with understanding the impact of implementing more efficient motor types.

Level 3 of the software analyses the energy savings possible from the implementation of a variable speed drive system to a pumping application. The variable speed drive design is achieved by first selecting suitable motor ratings, duty cycles, and process related pump flow rates (motor speed). The comparison of a variable speed drive system to simpler valve control is provided with the power consumption versus speed control graphical output provided by the software. Users can select different motor speeds to determine the best process design option based on energy savings and life-cycle cost analysis. Determining a suitable design or optimising for energy efficiency (or other targets) enables the task to be either simple or a higher level of complexity.

The Level 2 worksheet utilises data from Level 1 to ensure continuity of the *Deep Dive Case Study*. Future versions of the spreadsheet may enable Level 1 data to also carry through to Level 3 components. Further details of the operation and background theory for the *Deep Dive Case Study* simulation software are provided in the *Companion Document*.

2.2 Relevant industry sectors

The industry sectors included within this *Deep Dive Case Study* are the following:

- Heavy industry
- Electricity distribution
- Electrical and mechanical design

2.3 Relevant technologies

The key technologies to be covered in the *Deep Dive Case Study* include electrical energy metering, electrical distribution system components (transformers, conductors), industrial loads (lighting, motors), and variable sped drive systems. A range of scenarios below can be covered and tested in this case study:

- Estimate the energy use of different industrial plant equipment and power system components based on given design conditions and selection of duty cycles (time of use);
- Analyse how modifications to the overall plant demand profile can allow for more optimal distribution system components. This can be achieved through enhancement of time or use or duty cycles of equipment of through using different energy efficiency technologies, e.g. lighting products and the inclusion of variable speed drives;
- Calculate the power versus speed characteristics of valve controlled and variable speed drive controlled processes, illustrating the margin of energy efficiency gains possible;
- Determine the optimal cable size and select the transformer by using life-cycle cost analysis; and
- Understand the implication of selection of electrical distribution system components and associated losses, and quantify the total cost of ownership of devices.

Visual display of system output is included in the *Deep Dive Case Study* simulation and software platform to ensure the students have obtain some authenticity to the design decisions they are making. Refer to example below in Figure 2.3.

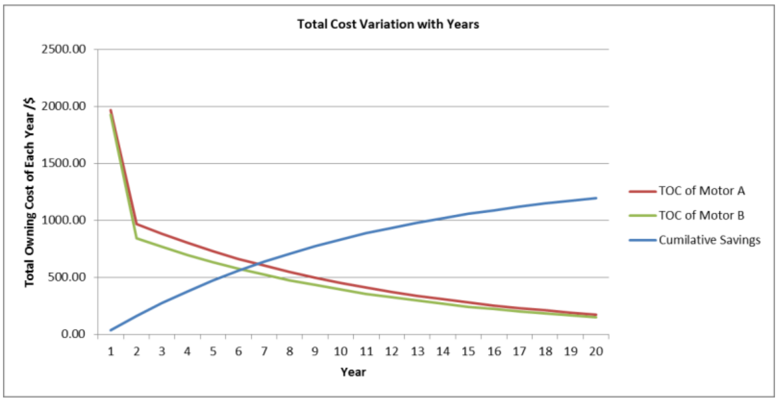

Figure 2.3 - Some information in the graphical interface of the sheet.

2.4 Graduate outcomes

The learning outcomes achieved from students will be dependent on how educators choose to utilise the *Deep Dive Case Study* simulation and software platform. Generally, students completing tasks utilising the *Deep Dive Case Study* will gain an understanding of the impact of various design decisions on industrial distribution system losses and associated load energy use, and gain knowledge of energy efficiency principles in general.

In the area of heavy industry energy utilisation and efficiency the key learning activities are as follows:

- 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;

In the area of heavy industry electrical distribution system components and loads the key learning activities are as follows:

- 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.

Mapping of graduate attributes to the Engineers Australia Stage 1 Competencies will be dependent on the manner and extent to which the *Deep Dive Case Study* is utilised. Preliminary mapping of competences against the perceived energy efficiency 'gap' attributes identified in 2012 Energy Efficiency in Engineering Briefing Note for participating in energy assessments and evaluating energy efficiency opportunities (Tables 1 and 2)[4] are provided below:

Table 2.1 – Engineers Australia Stage 1 Competencies addressed by *Deep Dive Case Study*

Selected perceived critical gaps (industry clustered themes) and mapping to EA Stage 1 Competencies[4]	EA Stage 1 Competencies[5]
Systems awareness, whole systems thinking, holistic approaches (Framing systems)	1.1, 1.2, 1.5, 2.1, 2.2, 2.3, 3.1
Collaboration, cross-disciplinary approaches, ability to work in a group	3.5, 3.6
Knowledge of measuring technologies and metrics, ability to identify inputs/outputs/losses	1.2, 2.1
Knowledge of energy principles, energy & relative amounts of energy needed for certain processes	1.1
Research skills	2.1, 3.4
Systems thinking - Identify all inputs and outputs, measurement and verification, create a baseline	1.5
Diagnostic skills, Critical thinking	1.5, 2.2, 2.3
Understanding of core engineering principles, including basic physics, thermodynamics and heat transfer, fluid mechanics, electrical machines	1.1, 1.2
Knowledge of EE technology	1.1, 1.3, 1.4
Financial education and evaluation skills, economic and business case analysis skills, ability to calculate expected Return on Investment (ROI)	1.1, 1.3, 1.4
Creative/ lateral thinking / Innovative thought processes, understand how and where to draw on external knowledge sources, capitalising on collaborative approaches/ team work	2.1, 2.3, 2.6
Reporting skills / documentations skills (potential opportunities, recording calculations)	3.2, 3.3, 3.4

[4] 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.
[5] Stage 1 Competency Standard for Professional Engineer, Engineers Australia, available from http://www.engineersaustralia.org.au/, [date accessed March 2014].

2.5 Engineering sub-disciplines

The engineering disciplines included within this case study are the following:

- Electrical
- Mechatronic
- Mechanical
- Process

3 Teaching guide

The *Deep Dive Case Study: Heavy Industry Electrical Energy Use and System Design for Energy Efficiency and Sustainability* teaching resource is designed to be delivered as either a self-guided learning tool, tutorial task, workshop activity, or subject assignment.

The *Deep Dive Case Study* software allows the student to investigate and evaluate the impact of various design decisions in regards to electrical system energy efficiency and sustainability. The software aims to be able to provide an understanding of design outcomes due to parameter and equipment changes without having to laboriously perform a number of intermediate detailed calculations. To this regard it enables the user to establish a more holistic viewpoint of design outcomes in relation to energy efficiency and sustainability.

3.1 Pre-requisite knowledge

As indicated in Section 2.1, the resource incorporates three different levels of technical details, knowledge and skills. The resource may therefore be utilised for demonstration purposes, short tutorial problems, or detailed investigations. The resource however is not designed to be an introduction into the heavy industry energy efficiency and sustainability topic area, and some previous knowledge of concepts related to electrical distribution systems and load energy requirements is required to be delivered before implementation. Alternatively, the resource could be utilised in the later stages of sustainability related topics or later stages of the engineering degree program without introduction.

3.2 Embedding within existing programs

The *Deep Dive Case Study* is designed to be implemented at the practise and demonstrate phases of the undergraduate programme[6]. To this regard it is expected to be embedded into 3rd and 4th year subjects of the undergraduate degree programme. However, educators may wish to implement components during the learning phase of the respective engineering degree if used for demonstration purposes or guided tutorials, following introductory knowledge of electrical system design and equipment energy requirements.

An example task utilising the *Deep Dive Case Study* is provided in the *Companion Document*. The task is specifically designed for an initial high level of classroom discussion, followed by individual work or activity in small groups, and then reporting back to the larger group. This structure suits workshop styled tutorials. Initial high level discussion could be used to outline the scope of the activity (rather than it being provided). Detail in the task is left vague specifically to promote this purpose. The procedure of defining scope with a client, undertaking investigation and analysis, and reporting back

[6] C. Desha, *Energy Efficiency & Engineering Education: Increasing Energy Efficiency Knowledge & Skills*, Briefing Note for Engineering Practitioners and Educators, Report for Engineers Australia and DRET, 31 August 2012.

to the client, fulfils the requirement to emulate a typical energy efficiency related engineering problem.

3.3 Catering for different audiences

3.3.1 Varying class sizes

The *Deep Dive Case Study* software has been developed using Visual Basic and Microsoft Excel. The software has a reasonably large file size but is otherwise easily portable to individual computers or distributed via web based applications. Thus implementation into varying class sizes is only restricted by the number of computers accessible by the students.

3.3.2 Multi-disciplinary audiences

Use of the *Deep Dive Case Study* with multi-disciplinary audiences is encouraged and was part of the design brief during development. The detailed calculations within the software are based around electrical, mechatronic, mechanical and process engineering. Depending on the relative experience of the students the detailed calculations may be analysed as part of the activity or omitted from the learning process (e.g. focus on lifecycle analysis). It is to be noted that the learning outcomes are focused towards engineering students specifically. Implementation beyond lower levels such as use as a demonstration tool to illustrate relationship between energy efficiency and equipment selection will require some knowledge of electrical distribution systems to be established.

3.3.3 Dealing with multi-disciplinary audiences

For multi-disciplinary audiences, depending on the experience levels of students, the Level 1 and Level 2 stages of the *Deep Dive Case Study* are proposed to be most appropriate. Energy use analysis will be relevant to all disciplines to establish knowledge of the basic energy efficiency proposition. Tangible and effective measures to alter the energy use of the selected plant equipment provide a suitable discussion activity for all disciplines.