Queensland University of Technology

Bachelor Of Engineering

BEB801: Undergraduate Thesis (Project 1)

Project Proposal and Progress

Feasibility of Low Voltage Direct Current Power Distribution

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Executive Summary

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1 Introduction

In most Australian buildings power is consumed directly from the grid. All appliances are connected to one switchboard but can be separated over various circuit breakers. Generally Australian appliances will use Direct Current (DC) electricity but the outlets provide an Alternating Current (AC) source of 240V at a frequency of 50Hz. Each device therefore requires an inverter that converts this signal into the required constant DC voltage and current specific to that device.

This project will consider the feasibility of converting a portion of power distribution from the standard 240V alternating current from the grid with an alternative solution. The considered option is utilising a low voltage direct current on a separate grid to power consistently low consumption devices such as lighting or electronics charging devices.

Alternative power generation systems will be considered as well as whether the new possibilities for generation and distribution methods could be used in applications larger than residential homes. The additional locations for this application that will be analysed are apartment, industrial and commercial complexes.

2 Background & Literature Review

2.1 Introductory Statement

Due to my personal experience working as a trainee electrical engineer for an electrical contractor I have a stronger understanding of power systems in the construction industry than most students at my level. This project topic has a fairly large scope and will require a broad understanding of the areas listen below.

- Power distributions systems
- Alternative electricity generation solutions
- Electrical safety mechanisms
- Australian standards
- Tariffs
- Direct current vs alternating current
- Converters and inverters

2.2 Literature Review

2.2.1 Current Power Distribution Systems

Power systems consist of four major sections; generation, transmission, distribution and loads. AC electricity is generated in power plants and sent through high voltage transmission lines to substations and distributed to switchboards for use in residential, commercial and industrial areas [2]. In order to transport electricity over large distances (excess of 2km) without severe losses, very high voltage and low current is used [2]. This is voltage is lowered and current increased by a transformer at the substation and again at the residence.

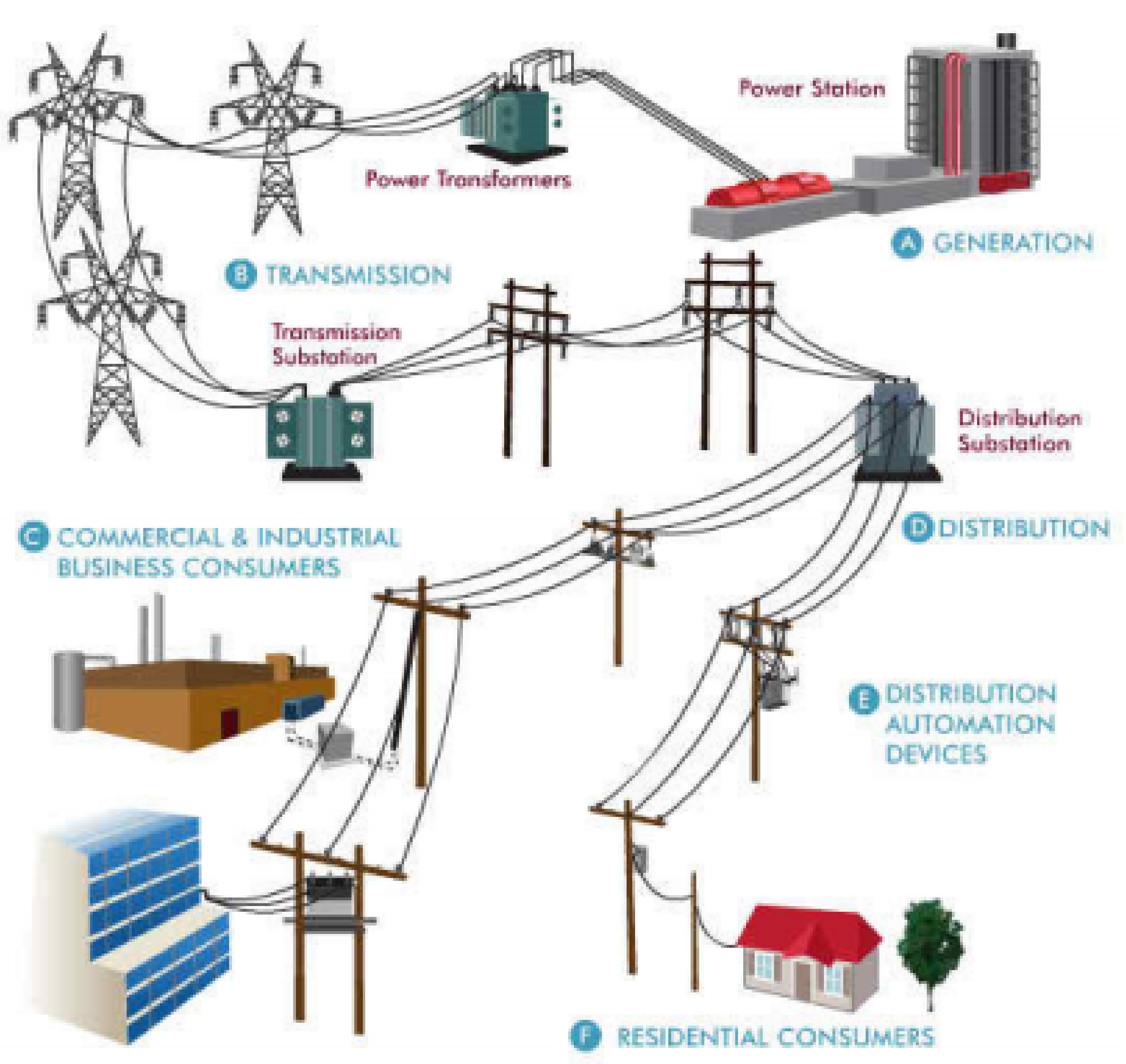


Figure 1: Current Power Distribution Methods [1]

2.2.2 Alternative Electricity Generation Solutions

In order to increase efficiency of power systems through utilising a low voltage DC subsystem, alternatives to drawing standard AC electricity from the grid must be considered. In Australia, a strong option for the generation alternative is photo-voltaic systems that are also known as solar panels. These systems will convert the sun's rays into electricity via a DC-DC converter and a DC-AC inverter and battery [3]. An important aspect is that the electricity is produced in DC and will require no inverter in a DC system.

Stuff on generators?

2.2.3 Electrical Safety Mechanisms

For electricity to each the home and be utilised for devices there must be safety mechanisms installed to ensure damage is not done to the user or devices. The protective devices requiring consideration throughout this project will be fuses, circuit breakers and switchboards [4]. These devices are placed through the circuit to protect the more expensive equipment closer to the transformer and grid. A fuse is a simple device that acts as a sacrificial lamb for the protection of the more expensive devices. An internal wire will melt when too much current flows through therefore interrupting the connection [4]. A circuit breaker is a smarter and re-useable version of a fuse that is triggered by overcurrent, overloads or shirt circuits to fulfil the same purpose [4]. The switchboard is a device that connects a home or building to the electrical grid and allows for individual circuits to be run for different purposes throughout the complex [4].

2.2.4 Standards

Australian standards will be an integral part of this project. Without adhering to the rules and regulations put in place, the devised system will not be legally allowed to be installed. There are three standards that will be relevant to this report; AS3000, AS3008 and AS3015. The AS/NZS 3000 covers the standards realted to electrical installations or wiring rules within Australia and New Zealand [5]. These standards will be the main reference point however there are the additional publications of AS/NZS 3008 which are the regulations specifically related to electrical installations and cable specifications [6]. The final standards taken into consideration will be AS/NZS 3015 which specifically disctates the rules with regards to electrical installations of extra low voltage direct current power supplies and services earthing within public telecommunications [7].

2.2.5 Tariffs

Tariffs will be an important considerion with the feasibility of this project due to the possibilities of cost reduction. User expenses could theretically be reduced by implementing a system off the grid. Government policies have been put in place in order to prompt an increase in investment in renewable energy sources [8]. Users are able to sell their unused generated electricity back to the grid to reduce their overall electricity bills or possibly profit if consumption is low enough. In Queensland, according to the SolarChoice website a feed-in tariff of $0.06/kWh can be earned [9]. By not connecting the photo voltatic panels to the grid, this tariff can not be received however there is the possibility that it is more efficient and will produce less energy loss by storing in local batteries and running simple circuits rather than feeding the grid [10]. The consideration will be whether the cost reduction in electricity bill will be worth the investment in the equipment and future cost reduction.

2.2.6 Direct Current & Alternating Current

A very broad and contextual understanding must be made about the differences between direct current and alternating current distribution systems. Compared with traditional AC designs, DC has the potential for large power supply capacity, smaller feeder loss, increased efficiency, more consistent power and more direct access to renewable energy solutions [11]. Alternating current is run to outlets at 240V, 50Hz and then devices are used to alter that source into whatever the device requires. Many household electronics such as computers, chargers, lighting and televisions operate internally at DC voltages meaning they each require either internal conversion circuitry or use a transformer between the powerpoint and device [12].

AC was originally depicted as the better choice for power distributions due to there being no method at the time for controlling DC electricity at the load causing large losses from the generator to device [13]. To remedy this, AC distribution was used due to efficienct transformers being developed to boost the voltage. AC remains the fundamental power type but DC is growing in popularity with improved converters and increased frequency of DC energy sources [13]. Utilising DC generation systems could also fulfill the power industry's obligation to increase the sustainability of their systems and be more environmentally conscious [14]. The required inverters to convert the AC supply into DC for electronics is reducing the efficiency (increasing voltage drop) of the overall system [13].

2.2.7 Low Voltage Direct Current

Towards the end of the 19th century, AC began used instead of DC in power distribution [15]. DC power is currently restricted to special applications such as telecommunications, electric vehciles and high-voltage direct current (HVDC) transmission [15]. Low-voltage DC power systems at 48V has been used fairly widely with telecommunications systems but is recently facing issues due to the high power requirements of computer system upgrades [15]. Studies have shown that the 48V system still remains more efficienct than a 270V DC or 200V AC but further investigation needs to be done into 230V and 325V through retrofitting existing low voltage AC installations [15]. Photo-voltatic generators are used frequently for these forms of power distribution systems as it can be powered directly or use simple DC to DC converters for different devices. Utilising a DC distribution system makes it easier to incorporate the local generation meaning not only could this be cheaper but if there are faults with the distribution grid, the separate micro-grid will be protected [14]. Using LVDC instead of AC has the ability to reduce load losses by being able to remove the diode drectifier and power supplies efficiency's would increase from not requiring to convert sources [15].

2.2.8 Converters & Inverters

Converters and inverters are electrical devices designed and constructed to convert current [16]. Converters are used to convert the voltage from AC to DC and inverters converter from DC to AC [16]. Inverters are used to convert the DC from solar panels to AC for transfer back into mains or to the necessary switchboard. An additional use for these is in Uninterrupted Power Supplies (UPS) where stored DC battery power [16]. There are three different types of converters and inverters;

Converters [17].

- Analog-to-digital converter (ADC): converts the input analog coltage to a digital value proportional to the magnitude of the voltage or current. An example of these would be a rotary encoder.
- Digital-to-analog converter (DAC): converts digital code to an analog signal. An example would be a computer sound card or digital music players.
- Digital-to-digial converter (DDC): converts one form of digital data to another.

Inverters [17].

- Square wave inverter: built from a DC source with four switches and a load, it produces a square wave output. This is the cheapest device but produces the lowest quality power.
- Quasi wave or modified square wave inverters: the output waveform is square and therefore not sine which is required for pure AC sine waves. These waves have a step between the square waves which can aid in minimising noise or harmonics that can cause problems with electrical devices.
- True sine wave inverters: the most expensive form of inverter. These aren't use actively due to the second option being more cost efficient.

2.2.9 LED Lighting

A large reasoning behind this project and the possibilities that it could allow for are the developments within LED lighting and increased efficiency of their electronics. It is very possible to design and create an energy efficient lvdv grid powered LED lighitng system with additional automation aspects and energy storage [18]. Typical lighting systems that are used in a lot of commercial or residential buildings are flurescent systems that are powered directly from standard 230V AC due to the devices' high efficacy [18]. When comparing an AC flurescent system and a LVDC LED system, the LVDC gid system requires sigificantly less power conversion due to the nature of LEDs and DC electricity which increases the overall effiency [18]. The image below additionally compares how lower wattage and power consumption is now able to produce far more light (lumens). This is allow fewer a similar amount of lights per room but they draw far less power [19].

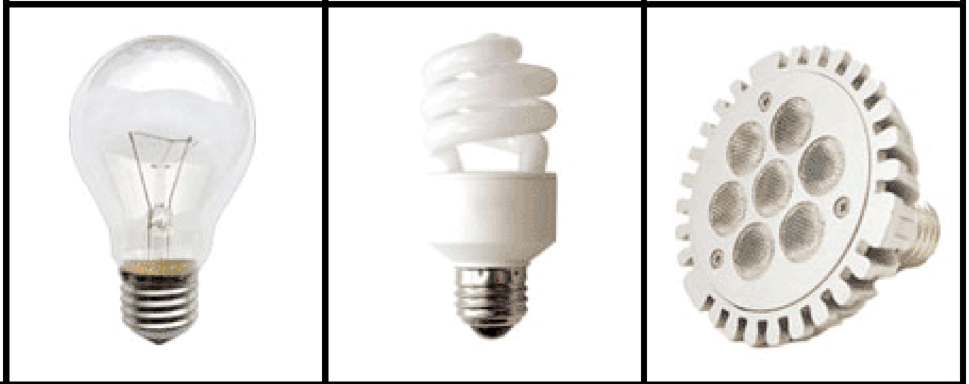
	Incandescent Bulb	CFL Bulb	LED Bulb
			
Wattage	40 W	9 W	7 W
Lumens	550 lumens	550 lumens	400 lumens
Lumens/Watt (Efficacy)	14 lm/W	61 lm/W	57 lm/W

Figure 2: Comparing Lighting Method's Efficiency [19]

2.3 Prior Art

For a thorough research project to be completed, devices that have already been designed, tested and created. With the popularity of DC power systems increasing in recent years, there have been an increasing number of academics assessing the possibilities.

3 Research Problems

The key problem that this research paper will be targetting is the feasibility of implementing a separate DC power distribution system for the specific purpose of powering LED lighting circuits and simple electronics. The possibility of this application will be tested through physical devices where possible or software simulations otherwise. In order to answer this key question, sub questions have to be separated and discussed. These are:

1. Can direct current power be a suitable alternative to alternating current when effiencies are compared?
2. Is 48V the most suitable option for this system?
3. Could a photo-voltaic system be implemented to power these circuits?
4. Will a separate circuit that powers the lighting in buildings be possible?
5. Could these proposed power distribution methods be implemented in residential, commercial and industrial applications?

4 Program and Design

Content [20].

4.1 Objectives

The objective of this reearch project is to attempt to answer the overall question of whether a low voltage DC power distribution system could be implemented. A secondary objective is to relate this project directly to renewable energy generation. Additionally it needs to be kept costs low and replace expensive construction of designs with realistic simulations.

4.2 Methodology

In order to complete this task within a timely manner and ensure all aspects are thoroughly considered and discussed, a clear guideline of tasks musts be followed. Additionally, these tasks will need to specifically address the objectives that the research proposal addresses. As discussed in Section 3, there are five broad questions that are being addressed throughout the two semesters of this thesis. The methodology of the thesis is based around a combination of physical and theoretical testing. A reliance on previous research and design recommendations will be important as low-voltage DC systems is an area that has been researched consistently in recent years with the increase in renewable energy systems and increasingly efficienct.

The five separate questions are related to the same solution. Initial stages of the project require extensive research at the possibilities and theories behind a purely DC system. Once a strong idea of the possibilities and previous papers were analysed a general analysis of whether or not 48V is the ideal voltage level is secondary. To do this, it will be predominately theoretical with voltage loss caclualtions over standard cable lengths. Once this is the decided the next stage can be followed. Photo-voltaic systems are a common consideration when wanting to directly generate DC power. This project will use resources available to assess the options with solar panels and whether each option is suitable for applications.

The next stage and the main application that this project will be assessing. Ideally, a prototype will be constructed and tested that simulates a photo-voltatic array's ability to generate DC electricity. Then a battery system and DC-DC converter need to be designed in order to power an LED circuit. The reason for a solar array simulation is that with the low budget of this project, buying solar arrays is not a solution. These devices needed to be designed, built and tested to learn the extent of cable length and number of electronics able to be powered. The final consideration is what applications the design could be used for; whether that be residential, commercial and industrial. In order to calculate this I can use my personal knowledge of power systems from my work role as well as access to industry power calculation software.

Testing will be done whilst at University with access to specialised equipment whereever possible. This will allow for quick access to the electrical store as well as experienced individuals close by for guidance. If a test is required, similar to how the Unversity structures their practicals, I will write a brief practical document including aim, background, equipment, steps and a method of recording data. Safety is of the utmost priority when performing experiments especially when dealing with power systems. Clear risk assessments will be required before any test can be performed.

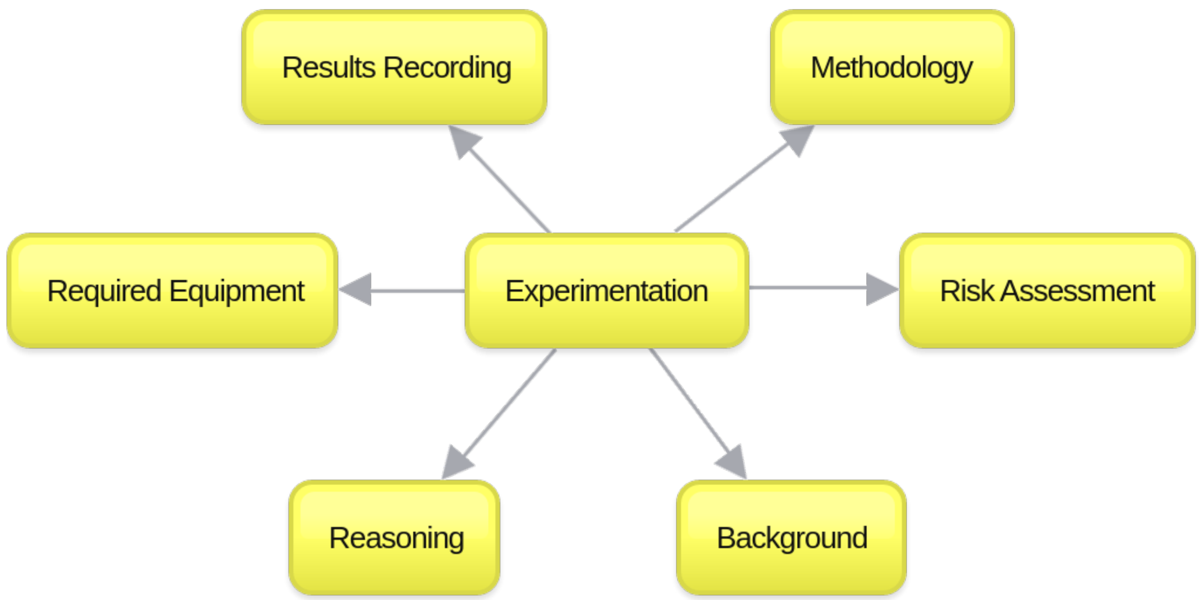


Figure 3: Considerations for a Practical Procedure

4.3 Research Plan

A large majority of the project will be through simulations utilising Matlab, PowerCad5, Dialux4.11 and PowerPac. This is due to power systems electronics being relatively expensive and large skale testing out of the financial scope of this project. Ideally, a full system would be built with Photo-Voltaic cells, battery, controller, DC-DC converters and connections to appliances, however finances are unlikely to allow this. Figure 4 below shows the individual areas that will require designs and testing.

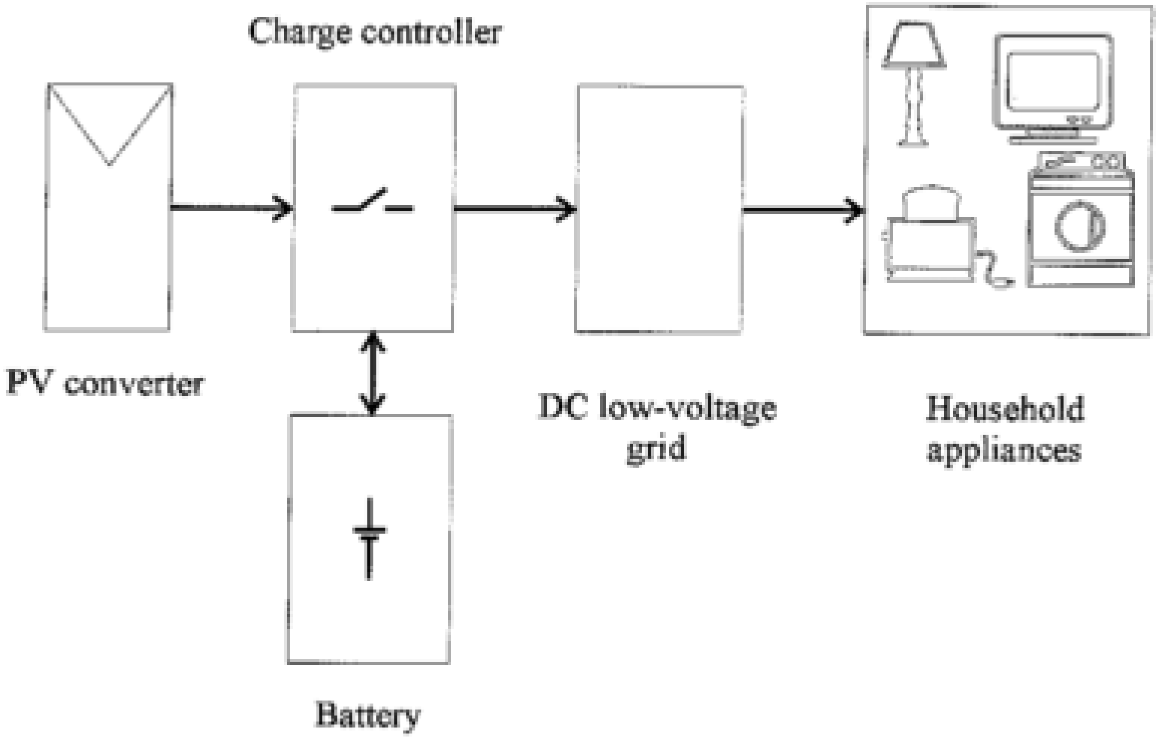


Figure 4: Initial Design Consideration for DC Home Power System [20]

The software will allow for data collection and spreadsheets will be utilised to track and manipulate this data. The benefit of using spreadsheets and possibly matlab is that formulas can be inputed and optimisation simulations therefore run to find the optimal value for variables. If simulations are not being run and physical tests being the chosen research, multimeters or computer interfaces will be utilised. If testing cannot be performed or simluated, additional research will be completed to find the closest solution possible. If this method needs to be done, it will explicitly stated in the final report that not all aspects could be physically tested.

Finally, this research plan will cover the testing procedure of the entire project. It could well occur that one stage of the project reveals information that negates a future consideration. If this comes to pass, the research plan will be altered to allow for a change of direction and different forms of testing or research.

4.4 Resources and Funding

The completion of this project will require a substantial amount of resources. Depending on the ability to perform physical tests, these monetary costs will increase substantially. As there is a posibility for industrial applications, those particular tests will be too costly to perform and simulations will be necessary. The University facilitating this research project will allocate $50 for each student through purchase order applications. This value will be taken into consideration when designing testing mechanisms. In the event further testing must be done, an application can be put forward to the supervisor and University for additional funding. If this is rejected and the project would substantially benefit from the purchases, it is to the discretion of the student to personally fund the purchases.

There is an additional benefit of the University Electrical Store located on the Garden's Point Campus. Items can be ordered through them or purchased for less cost than on the retail market. Additionally, if the item is cheap enough they can provide it for free. The benefits of this will certainly be considered throughout the completion of testing and feasibility study.

4.5 Gantt Chart

Appendix 1 and 2 outline the Gantt Chart that has been produced for this report. A software package named Microsoft Project exists that is specifically designed for producing technical Gantt charts for large scale projects. It allows for resources to be allocated to specific tasks and dependent jobs to be interlinked.When working within a team, this resource can be an immense benefit. This project is being undertaken solely by one student and will not require the management of a team. Due to this, Microsoft Projects' features will be wasted on this task. Overall, the best option would be a simple excel timeline.

The tasks were be split into days and University weeks. It was ensured to include the holidays that Universitiy allows. This project does not simply end upon the completion of this semester. BEB801 is concluded on November 4th at the end of Week 14 but BEB802 is the subject allocation to finish off the second half of this project. The Gantt chart will focus on the first half of the thesis. Additionally, the benefits of completing these subjects from Semester 2, 2016 to Semester 1, 2017 is that there is the additional time from summer holidays to account for. I will be overseas for an extended period of time throughout these holidays so a portion of the time cannot be used towards this project. There will be regular access to a stable internet connection whilst on holiday.

The four major deliverables for the first half of this project are the library assessment, project proposal, oral presentation and progress report. These 4 deliverables are what have outlined how the Gantt chart was created and which tasks were given how much priority. Throughout design projects and personal experience I have found that to ensure major deadlines are reached, I set personal due dates a minimum of three days earlier. This means

Task Name or Phase	Deadline
Project Definition	Week 3
Library Assessment	Week 4
Initial Research Phase	Week 5
Initial Design Phase	Week 8
Prototype Construction	Week 11
Oral Report	Week 14
Written Report	Week 13

Table 1: Major Milestones of Project

5 Final Discussion & Conclusion

Content

References

[1] A. S. Active and P. Filter, "Transmission and Distribution Components," *Quadrennial Technology Review 2015*, no. January, pp. 1–22, 2015.

[2] M. Amin, Y. Arafat, S. Lundberg, and S. Mangold, "Low voltage DC distribution system compared with 230 V AC," *2011 IEEE Electrical Power and Energy Conference, EPEC 2011*, pp. 340–345, 2011.

[3] L. Pillay and K. S. Karimov, "Photo-Voltaic System," in *3rd International Conference on Electrical & Computer Engineering*, no. December, (Dhaka, Bangladesh), pp. 28–30, ICECE, 2004.

[4] United States Department of the Interior, "Methods for Coordinating System Protective Equipment," *Facilities Instructions, Standards, and Techniques*, vol. 3-9, no. December 1991, 2000.

[5] Standards Australia, "AS/NZS 3000: Wiring Rules," pp. 1–21, 2007.

[6] Standards Australia, "AS/NZS 3008: Electrical Installations," pp. 1–136, 2010.

[7] Standards Australia, "AS/NZS 3015: Electrical Installations of Extra Low Voltage DC Power Supplies and Service Earthing Within Public Telecommunications Networks," pp. 1–61, 2004.

[8] T. Nelson, P. Simshauser, and S. Kelley, "Australian Residential Solar Feed-in-Tariffs: Industry Stimulus or Regressive Form of Taxation," *Economic Analysis and Policy*, vol. 41, no. 2, pp. 113–129, 2011.

[9] SolarChoice.net, "Which electricity retailer is giving the best solar feed in tariff?," 2016. http://www.solarchoice.net.au/blog/which-electricity-retailer-is-giving-the-best-solar-feed-in-tariff/?Qld.

[10] S. Antoniou, A, Tzimas, A, Rowland, "Transition from AC to DC Low-Voltage Distro Networks," *IET Generation, Transmission & Distribution*, vol. 9, no. 12, pp. 1391–1401, 2015.

[11] Z. Liu and M. Li, "Research on Energy Efficiency of DC Distribution System," *AASRI Procedia*, vol. 7, pp. 68–74, 2014.

[12] P. Paajanen, T. Kaipia, and J. Partanen, "DC supply of low-voltage electricity appliances in residential buildings," in *20th International Conference and Exhibition on Electricity Distribution (CIRED 2009)*, no. 0692, pp. 1–4, 2009.

[13] M. Starke, L. M. Tolbert, and B. Ozpineci, "AC vs. DC distribution: A loss comparison," *Transmission and Distribution Exposition Conference: 2008 IEEE PES Powering Toward the Future, PIMS 2008*, vol. 1, no. 1, pp. 1–7, 2008.

[14] M. Starke, F. Li, L. M. Tolbert, and B. Ozpineci, "AC vs. DC distribution: Maximum transfer capability," *IEEE Power and Energy Society 2008 General Meeting: Conversion and Delivery of Electrical Energy in the 21st Century, PES*, pp. 1–6, 2008.

[15] D. Salomonsson and A. Sannino, "Low-voltage DC distribution system for commercial power systems with sensitive electronic loads," *IEEE Transactions on Power Delivery*, vol. 22, no. 3, pp. 1620–1627, 2007.

[16] R. A. Krishna and L. P. Suresh, "A brief review on multi level inverter topologies," in *2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT)*, pp. 1–6, 2016.

[17] Diffen.com, "Converter vs inverter," 2016. http://www.diffen.com/difference/Converter-vs-Inverter.

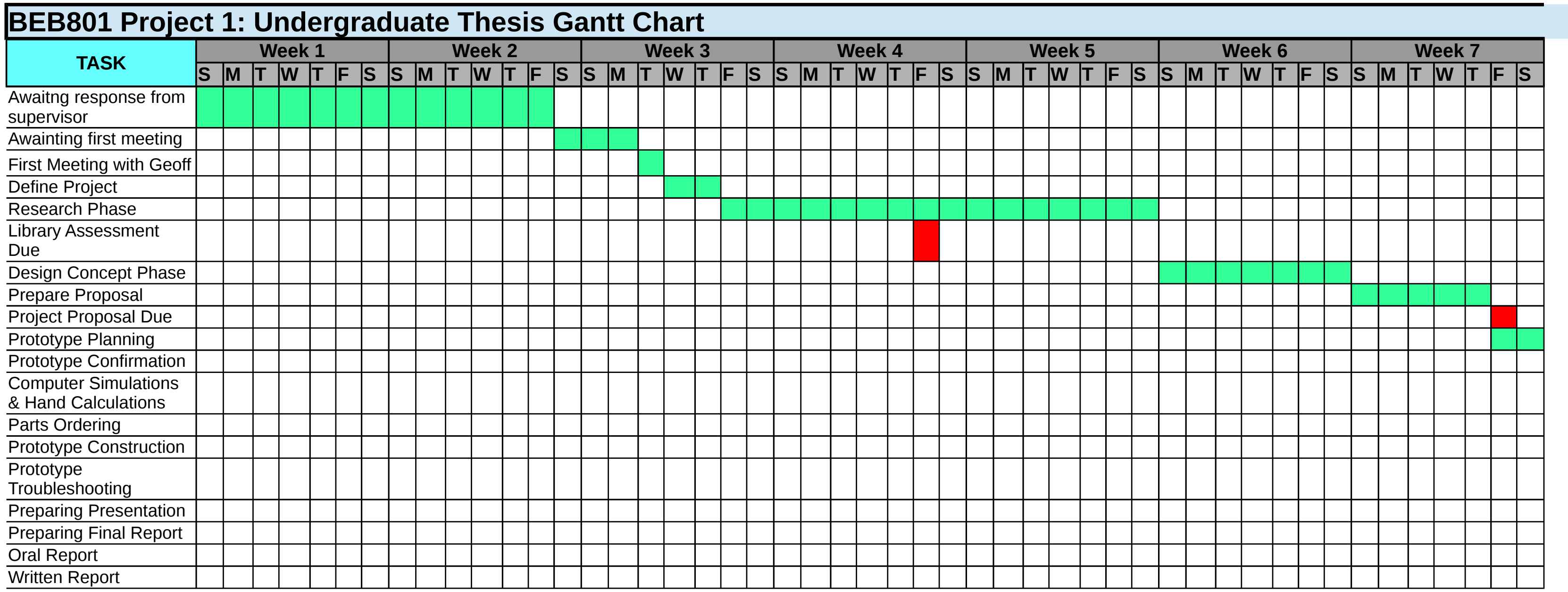
[18] L. H. Koh, Y. K. Tan, Z. Z. Wang, and K. J. Tseng, "An energy-efficient low voltage DC grid powered smart LED lighting system," *IECON Proceedings (Industrial Electronics Conference)*, vol. 2, no. 11, pp. 2883–2888, 2011.

[19] E. Revolution, "Lumens and light output," 2016. http://www.eco-revolution.com/lumens-and-light-output/.

[20] J. Pellis, *The DC Low-Voltage House.* PhD thesis, Eindhoven University of Technology, 1997.

Appendix 1: Project Gantt Chart - Page 1

Sheet1



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Appendix 1: Project Gantt Chart - Page 2

Sheet1