Griffith School of Engineering

Griffith University

6007ENG – Industry Affiliates Program

Impacts of EV Charging on Strata Building Distribution Infrastructure

Kulima Panapa s2919305

Monday 29th May 2017, Semester 1

Wattblock

Scott Witheridge

Sascha Stegen

A report submitted in partial fulfilment of the degree of Sustainable Energy Systems Engineering

EXECUTIVE SUMMARY

This project investigates the impacts of EV charging on strata building distribution infrastructure. The key focus area of this project was to understand the impacts caused on switchboards under different charging levels during different times of the day.

Using average residential demand profiles in Queensland and case study energy billing data, a demand profile was modelled to simulate the buildings expected demand throughout the day. Determining the maximum demand for the case study building by way of calculation allowed for modelling of key electrical functions onto each phase. Implementing level 2 trickle charge, level 2a fast charge and level 3 rapid charge rates for EV charging allowed the impacts of EV charging to be measured during the best and worst-case scenarios for demand. Overloading was observed under three conditions; 1) charging too many EV at one time, 2) charging at a higher charging level than necessary and, 3) charging during peak times.

EV charging durations were also looked at for each charging level in regards to three EV – Tesla Model S, BMW i3 and Nissan New Leaf. These durations were utilised in conjunction with the best and worst-case scenarios for demand to find suitable charging times. Payback periods for EV chargers were also considered for insight into uptake in strata. Total cash-flows were calculated using the difference between annual fuel cost for each vehicle and the Mazda 3. Investment costs were based calculated using capital and installation figures from an Australia supplier.

ACKNOWLEDGEMENTS

This paper could not have happened without the industry supervision from Scott Witheridge and the staff at WattBlock. A special thanks is dedicated to them for their ongoing feedback and advice towards this project. To my industry supervisor Scott, the skills I have learned from you will be kept close at hand when conducting myself professionally. I take away valuable memories in knowing that for a brief period I was once a part of such an exciting and innovative movement.

To my academic supervisor Sascha, your guidance during this project was paramount and decisive in key areas. Thank you for not only your tutelage amongst the tight confinements of your busy schedule but also your teachings as a lecture. I found your laboratory classes the most engaging part of my degree.

Lastly but most importantly, a great appreciation is dedicated to Vana my beloved fiancé, family and close friends for the constant support throughout this thesis and my entire degree. The support and encouragement you all have shown has meant the world to me through this journey and I am proud that I was able to finish despite the many obstacles that stood in my path. To these people I owe my deepest gratitude.

TABLE OF CONTENTS

1 INTRODUCTION

Australia's climate change target developed during the Kyoto protocol was to reach a 26% - 28% reduction in emissions on the 2005 levels by 2030 [1]. A crucial part of Australia's target lies within the transportation sector as it makes up 17% of the nations carbon inventory [2]. In reaching this target, it is suggested that electric vehicles (EV) could play an important role – significantly in the residential sector and in particular, multi-storey apartment buildings (strata).

Strata is a type of property ownership title [3]. It allows different owners to own one or more apartments within a building. Ownership of common areas and facilities such as car parks, gardens, pools and gyms are usually shared between each owner. In August 2016 there were 1,312 approvals for these types of buildings. This is expected to greatly increase the number of strata buildings in Australia [4].

1.1 WattBlock

WattBlock is a Sydney based company who's purpose is based upon enhancing energy savings in strata buildings. By conducting energy assessments utilising detailed energy reports, WattBlock encourages energy efficiency in all aspects of strata buildings through cost-effective energy projects - usually targeting a specific area of energy-use like lighting. Other projects such as water saving and Solar PV are also provided given they are feasible and sustainable.

The 'lowest hanging fruit' ideology is an approach applied to developing project proposals and typically adopted to promote strata managers to actively engage in reducing their energy consumption effectively and efficiently. This creative innovation has lead WattBlock to become one of the most effective companies in this field throughout Australia. With unique differences in technique to traditional styled energy audits, WattBlock was awarded the 2016 NSW member 'Innovation Of The Year' award from Strata Community Australia (SCA).

Social and industry recognition has allowed WattBlock to grow outside NSW. Expanding a branch office into Queensland has provided a wider cliental base, where the areas of the Brisbane CBD, Sunshine Coast and Gold Coast contain a dense concentration of strata buildings.

Through its positive practice of sustainability, WattBlock has identified the importance of EV in strata buildings and is continuing its growth as a leader in strata sustainability by imploring EV research studies. As such, this study focuses on assessing the impacts of EV charging in strata buildings for future EV implementation and was developed to promote strata managers to be proactive in the area of EV management as another business strategy.

1.2 Electric Vehicles

Electric Vehicles (EV) differ from combustion-engine vehicles (CV) in that they are powered completely by electrical energy stored in battery units thus eliminating the need for a tailpipe common in all CV. Improved battery technologies have enabled EV to gain traction within the automotive industry with automobile companies developing their own unique EV products. Table 1 below shows a list of companies that have available EV products and companies who are still developing their first line of release.

Table 1. – Company Models for EV.

Company	Model
Tesla	Model S, Model X
Nissan	New Leaf
BMW	i3
Ford	Focus
Honda	Fit-EV
Hyundai	IONiq EV
General Motors	Bolt, Spark
Volvo	C30
Mitsubishi	I-MIEV

As EV are driven they consume electrical energy that is then replenished through charging. In most cases the charging process requires a charging unit and a charging connection point that provides direct access into the grid. Similar to hybrid EV, some EV can also be plugged into a power socket and charged. However, for the purpose of maintaining battery life, usually a charger is necessary to control the charging rate through the current drawn by the EV. Using a charger also presents the opportunity for metering to happen in the charger if not configured already. For the purpose of this project, AC charging will not be covered.

1.3 Description of Project

This study will focus on the impacts of EV charging on strata building distribution infrastructure. It is believed that focus for this study will help inform the strata community to make key decisions regarding EV charging implementation and help accommodate EV uptake in strata communities.

With the amount of high-rise apartment building construction happening at present time, the strata community will only expand. Strata buildings are the focus of WattBlocks purpose and thus the purpose of the study should naturally align. Due to the higher degree of complexity in electrical systems that apartment buildings have over stand alone dwellings, exploring the impacts of EV charging in strata buildings could be of great value to literature with in this area. This will be more closely looked at in the literature review section of this document.

For the purpose of this study, only EV will be looked at. This is because compared to hybrid technology, with the different charging requirements of EV batteries, the related impacts are expected to be different and so this study explores those impacts. The type of EV used for this study are light passenger vehicles only. As strata buildings are typically places of residence, it is assumed that the travel to and from strata buildings will be predominantly private transport. Although electric bikes are gaining traction within todays EV market, they will be excluded from the realms of this study. The EV models used in this project are explained in the methodology section.

The distribution infrastructure assessed in this study will be switchboards. It is often the case that more than one switchboard is used for larger buildings in which different groups of electrical equipment are connected to the same switchboard. In strata buildings, there are usually at least two switchboards: 1) for the apartments and, 2) for the common electrical equipment. When installing EV chargers, supply will typically be distributed from the nearest switchboard. For this study, it is assumed that the EV charger supply will come from the common property switchboard. This also serves as a way to gain insight into the impacts on allocated services on the common property switchboard.

1.3.1 Objectives

In judging the typical electrical design process of past strata buildings, it was discovered that they were not inclusive of any EV charging technology considerations. This study serves a purpose as to explore the different impacts of EV charging on switchboards. By analyzing a case study strata building, data regarding average energy consumption applied to demand profiles will be used to understand the impacts of EV charging at different charging levels. EV charging durations will be assessed at different levels to investigate impacts further. Lastly EV charger payback period will be looked at to for insight into EV costs.

The objectives of this study are as follows:

- Model different charging levels to analyse EV charging impacts on switchboards in strata buildings
- Charging duration impacts on switchboards
- Payback period for EV chargers

1.3.2 Constraints and Assumptions

Due to the stochastic nature of driving, assumptions were made to average out the driving time and charging time for modeling. This was expected to make the calculations simpler. With this assumption however came the constraint in which the model would have less accuracy.

It was also assumed that no charging outside of the home charging bay had taken place. Although this was recommended in the literature, knowing the impacts of EV charging is suggested to be better understood under slightly more extreme conditions in sense of the best and worst-case scenario perception. Assumptions were also made regarding what time of day the EV would be charged to estimate the average demand for energy during that time.

2 LITERATURE REVIEW

In this section, various areas were reviewed in search for relevant material. Areas such as strata building statistics, EV uptake, EV impacts on distribution networks and EV charging were considered useful for drawing parallels from for discussion in the results section. Research methods for particular articles were highlighted to contribute to the methodology section of this paper.

2.1 Strata

The term ‘strata’ describes a type of title in property ownership. In contrast to company title, strata title is defined when ownership of different lots or apartments within a particular building belongs to different owners. These owners also share ownership of the common property facilities such as car-parking levels, gardens and recreational areas etc. Strata title ownership also extends to commercial and retail properties as well [3].

Strata buildings in Sydney recently accommodated for half of all residential sales and leases made. This shows the significance of this type of property within modern society and the necessity to target strata buildings to be advocates of energy efficiency.

In Brisbane, as of the 2011 census, the number of flat, unit and apartment buildings recorded accounted for 13% of total dwellings [5]. Of that 13%, a further 57% were buildings three storey or higher. This points out that in 2011 at least 7% of the total dwellings in Brisbane were multi-storey apartment buildings [5]. This figure when taken in the context of strata means that potentially 7% of all residential buildings could be strata buildings. What should be noted is that although multi-storey apartment buildings only accounted for 7% of all dwellings, these buildings are medium to high population density.

Building approvals in Brisbane suggest that there will be an even greater growth in strata buildings in the coming years. From the month of August 2016, it was recorded that 1,311 applications for construction had been approved for buildings with three or more floors [4].

While looking into strata building statistics it was identified that the Australian Bureau of Statistics did not include any significant figures for strata title ownership or strata buildings. Although it maybe too specific within such a broad range of data collection, due to the difficulties of interpreting from a population density count the amount of strata buildings there are, an accurate count should be taken nation wide.

Exploring this topic in relation to energy efficiency, let alone EV charging, reveals that this is an area that is scarce on academic literature. Despite the amount of organisations that are basing their work on enhancing strata building efficiency through energy auditing, finding peer-reviewed material and credible sources is challenging.

Researching apartment building electrical design and circuit arrangements, revealed minimal studies. Most studies conducted were regarding the material compositions of buildings, heating and cooling efficiency methods [6][7] and general energy efficiency in multi-apartment buildings [8]. While more specific topics were revealed, the Australian New Zealand standards (AS3000 Electrical Installations) for electrical wiring guides illuminated four methods towards determining the maximum demand of a building in Australia [9]. These methods were calculation, assessment, measurement and limitation.

While researching the current electricity load curves for apartment buildings, no specific material was found. However, in doing this it was identified that the Australia Energy Market Operator records the average residential electricity demand every five minutes as an average across each state in Australia [10]. From this data figure 1 below was produced. It shows the average Queensland residential load curve over a 24-hour period.

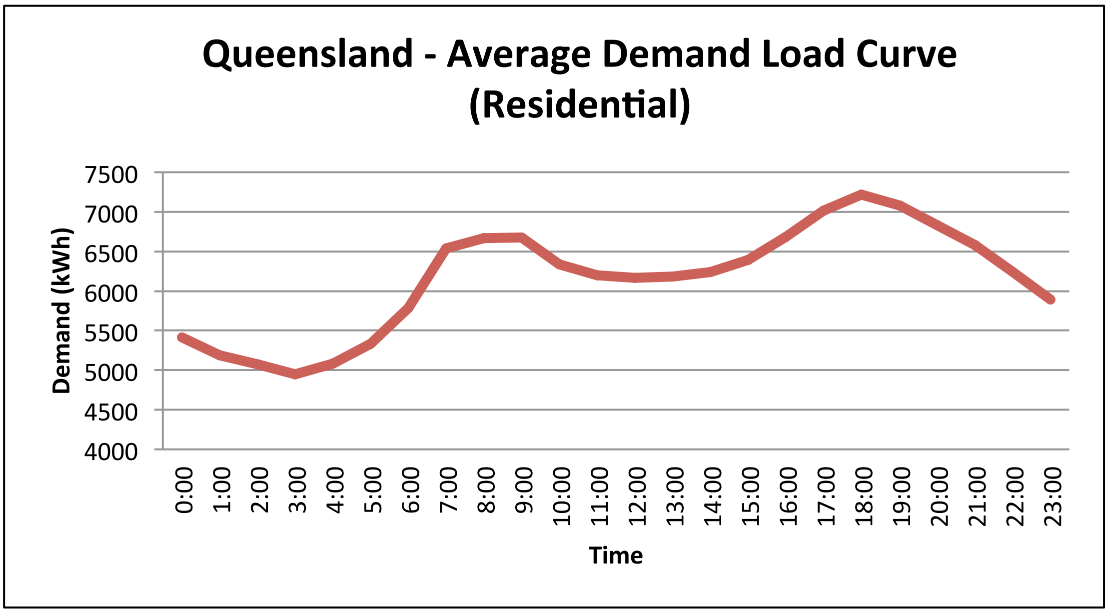

Figure 1. – Average energy demand in Queensland on May 10th 2017.

A report from the Department of Industry, Innovation and Science depicted data for Australian energy consumption by industry. Table 2 shows the breakdown of the countries energy consumption by sector in descending order between 2014-2015. Leading the consumption is electricity supply followed very closely by the transportation sector.

Table 2. – Energy consumption and annual growth factor by sector for 2014-2015 [11].

Sector	**2014-2015**		**Average Annual Growth**
	PJ	Share (%)	10 years (%)
Electricity Supply	1,666.9	28.2	-0.4
Transport	1,612.9	27.2	1.7
Manufacturing	1,147.1	19.4	-0.8
Mining	520.7	8.8	6.0
Residential	456.0	7.7	1.0
Commercial	336.2	5.7	2.4
Agricultural	104.4	1.8	0.8
Construction	27.2	0.5	0.4
Other	48.2	0.8	-5.1
Total	5,919.6	100.0	0.7

What is interesting within this data is the average annual growth data in 10 years time that shows an increase of 1.7 % for the transport sector. In comparison, electricity supply shows a reduction of -0.4 %. The origin for this data fails to consider a few things. It doesn't take into consideration EV uptake, large-scale renewable integration into the grid and residential energy storage. However, by going with the trends that this data has presented, it can be interpreted that energy consumption in the transportation sector will increase but the role EV will play is unclear.

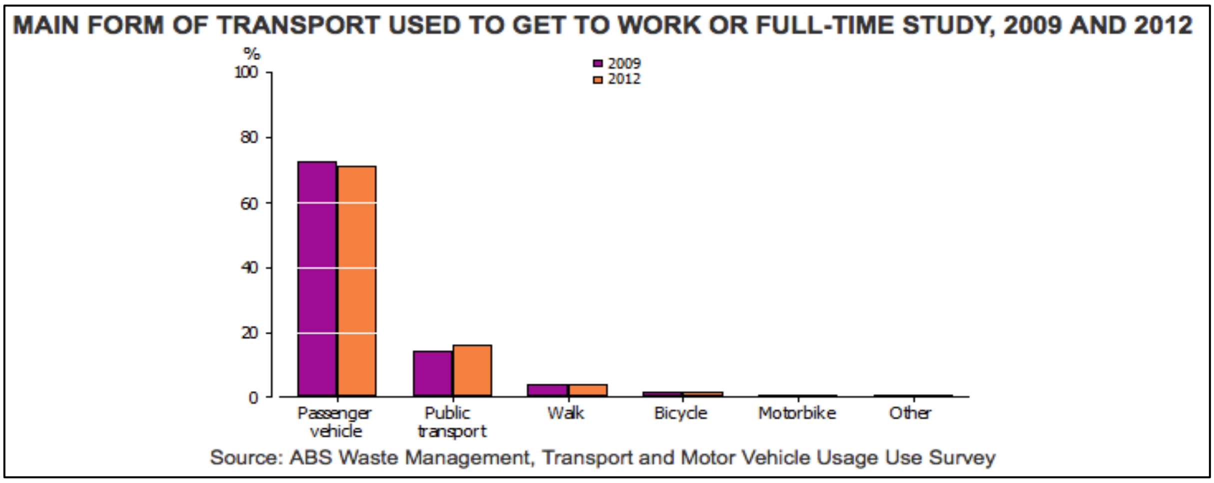

Figure 2. – Passenger Vehicles used for work and full-time study in 2009 and 2012 [12].

Although the role of EV in the future of transportation energy consumption is unclear, driving statistics regarding vehicle use is important. The data displayed in figure 2 for passenger vehicles used to commute for work and full-time study in 2012 shows that about 7 in 10 people primarily used a passenger vehicle (private vehicle). Furthermore, it was found that 88% of people use their own vehicles for driving to places outside of work and study. This shows the use of passenger vehicles is the preferred choice compared to other modes of transportation. Considering these factors and the forecasts previously mentioned, it could be expected that EV will soon replace a significant portion of the cars currently used. The figure 3 below discusses the types of vehicles that currently populate the roads.

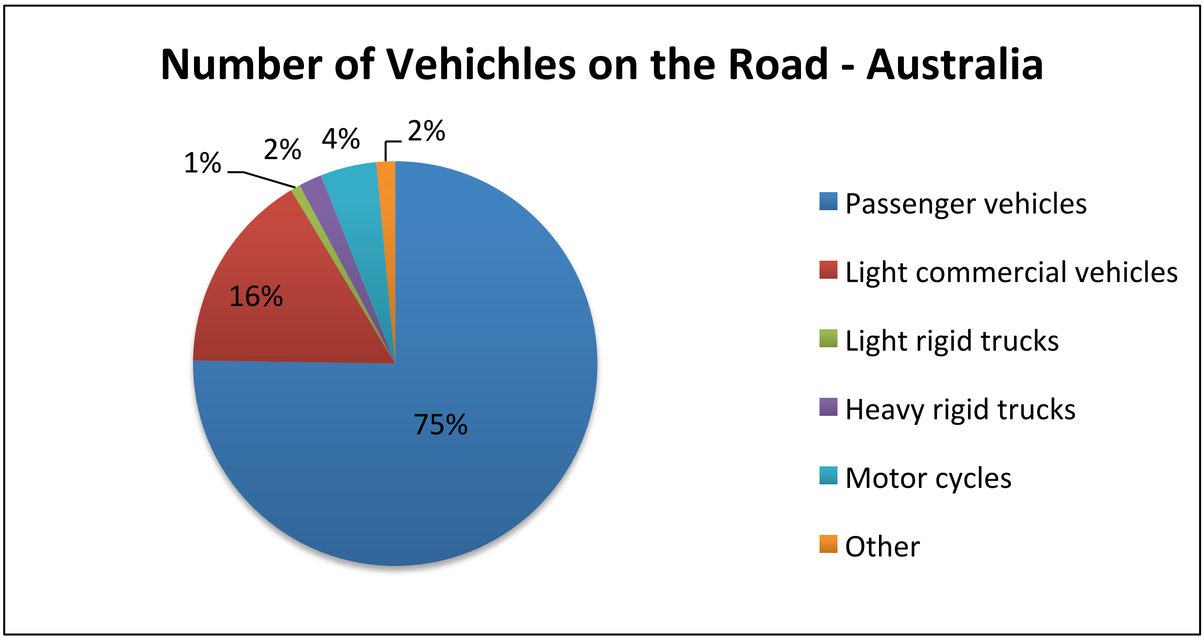

Figure 3. – Number of vehicles on the road by type in 2015 [13].

The ABS Motor Vehicle census for 2015 revealed that 75% of the vehicles on the road in Australia are passenger vehicles. Again, it can be seen that there is a significant number of vehicles that could potentially be converted to EV for the same use. Comparing these figures to the energy consumption figures in table 2 shows that passenger cars will have the largest impact in transportation emissions and energy consumption in the future.

2.2 EV uptake

Due to the Australian governments 2030 climate change targets, the attractiveness of EV is steadily growing. The target states that by 2030 there will be a 26-28 % drop in emissions on the 2005 levels [1]. Although countless speculations argue that this target will not be reached as a result of the lack of long-term policy change towards emission reduction, EV is still projected to account for one in five vehicles in just 20 years time [14].

Forecasts for EV uptake were predicted to have a steady increase over the first ten years due to a number of factors – gradual decrease in EV purchase price, increased availability by manufacturers and the price difference between petrol and electricity [14]. Figure 4 displays the expected number of EV to be driven throughout the next 20-year period. By 2036 it is forecasted that there will be at least 2.5 million EV purchased and used in Australia.

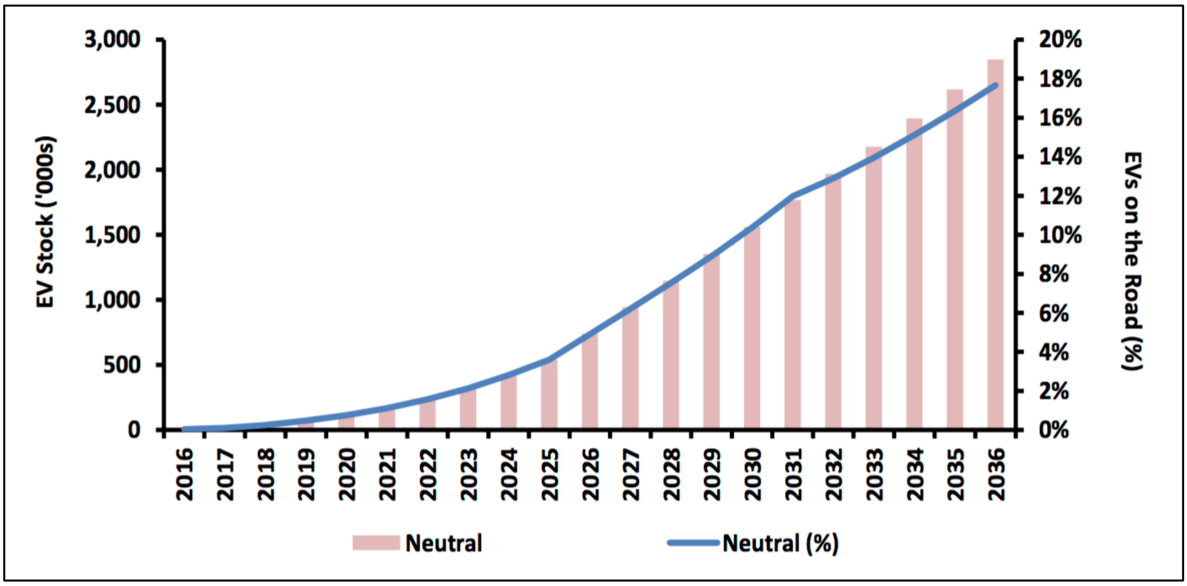

Figure 4. – EV uptake in Australia from 2016 to 2036 [14].

The study briefly discusses the grid consumption with in the projections for EV uptake where it was forecasted that with addition of EV drivers, total consumption would increase by 4%.

From the viewpoint that of the EV expected to be used being almost one fifth of total vehicles driven, the increase on electricity consumption is fairly moderate.

It is interesting that one of the main uptake factors is driven by the difference between the price of electricity and the price of petrol. This factor should be looked at more closely in relation to taking into consideration the ever changing Australian Energy Market and the policies that seem to be absent in the market structure to keep prices from escalating.

A study conducted by the National Transport Commission investigated emission levels for light vehicles in Australia measured in grams per kilometer of CO_2. The quantitative study found that there were a total of 942 EV sales in 2015. Despite the extremely low percentage of sales, EV cars had the lowest level of emissions intensity compared to petrol, LPG and diesel powered cars [15].

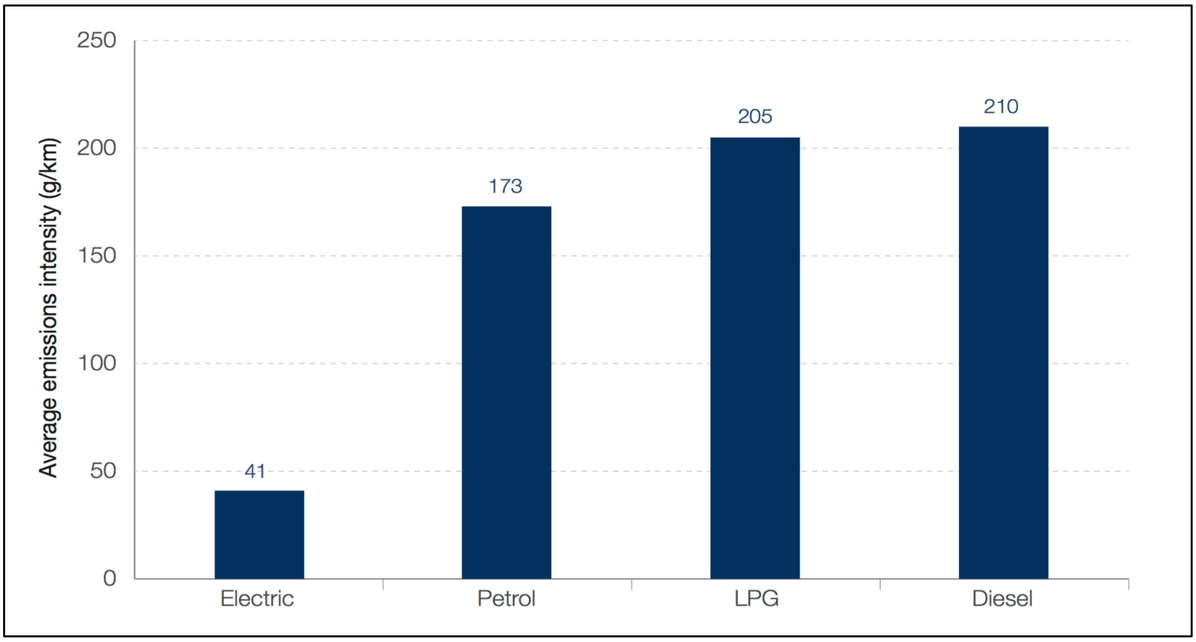

Figure 5. – Average emissions intensity by fuel type [15].

Relating this back to the Australian government targets for 2030, figure 5 shows that there is a massive difference in emissions between todays most common modes of transport – a difference of at least 120 g/km of emissions compared to the next lowest emitter.

Another paper explored the total environmental friendliness of EV use from generation to tailpipe emissions in the US. It sought to provide a more meaningful quantification of well-towheel energy uses, relying on a mathematical and computational based method. It found that EV might not be as green as originally thought at this current time [16]. Compared to combustion engine vehicles, the emissions created from fossil fuel power stations create a higher emission value for EV. A matter of interest here would be to take into account the amount of large-scale renewable generation that is planned for the grid and factoring that into the cumulative emissions calculation or the shaving that would occur if private renewable generation is used.

2.3 EV Charging

When investigating current literature regarding EV charging, a plethora of literature was found. Many topics had relevance in relation to the core direction of this review however only the most recent key articles were used. A review of the material has been constructed highlighting and evaluating the current literature and missing areas regarding EV charging. The main areas of interest within EV charging associate with the impacts on the grid, voltage stability and charging systems.

It was recognized that from the literature available, only one case explored EV charging in residential buildings. The focus was around different charging strategies. For this work, parallels were drawn from the EV charging articles to expand on the limited knowledge regarding the narrow topic.

It is expected that the absence of material relating to EV charging in apartment buildings and strata be because this area of research is very specific. By reading through the abstracts of many articles related to EV charging, it can be seen that the impacts on the grid and to distribution infrastructure, charging strategies, environmental factors and power system stability are the more commonly discussed topics. Although this is vitally important for the energy industry and the safety of electricity supply upon EV implementation for all consumers, it could be argued that a more critical investigation towards strata building distribution infrastructure should be made so that EV drivers in strata understand the processes, risks and safety issues associated with EV charging in the future.

Vehicle-to-Grid (V2G) technology works by feeding the grid from unused EV batteries when needed. What this does is increase the potential for power within the grid, acting as a temporary generator. In theory this increases the efficiency and reliability of the grid decreasing reliance on fossil fuels and simultaneously utilizes EV in a different dynamic [17]. Although this sounds very beneficial for the energy industry, as with all new concepts and ideas, standards and policy drivers are restricting V2G from being implemented today. Unfortunately as a result of this, there are currently no cases where V2G can currently being implemented publicly in Australia and no national-based case studies to support it. Further disadvantages of V2G systems relating to the impacts of grids have been reviewed.

The potential of EV are highlighted in [18] when discussing the modeling and simulation of V2G micro-grid systems under different connection conditions. Using a software-based methodology to model the network tested, simulations were conducted under level 2 fast charging conditions (refer to table 1.2). A closer look was made into the bus systems in place during the simulation to observe any relevant effects where no major issues were found. It was found that at the transmission level, V2G technology doesn't pose problems of any real consideration. However, at the distribution level it was found that large-scale implementation of EV calls for network changes especially regarding their management and protection.

A similar paper that looked at V2G systems revealed that there are factors that present arguments for and against implementation in distribution networks. The paper also reviewed types of charging strategies and the associated impacts [17]. The types of charging and the factors found are presented below in table 2.2.

By adding V2G system options into EV charging networks, various benefits such as power regulation, load balancing, current harmonic filtering and peak shaving can be achieved However, it is highlighted that this concept can also lead to battery degradation meaning reduced battery lifetime and storage capacity. V2G also creates the need for infrastructure upgrades and communication between EV and the grid to prevent voltage and frequency disruptions. It concluded by illuminating that the application of V2G systems have progress to be made in terms of smart charging systems and infrastructure upgrades but there are economic and grid benefits to be made also.

In support of the idea presented in table 3, a study investigating optimised charging strategies found that there could be up to 50% cost savings on charging. The study used mathematical algorithms coupled with simulations of charging times and battery state-of-charge (SOC). The study encouraged charging during off-peak times and consciously arranging an appropriate charging time to save on charging costs [19].

Table 3. – Charging strategies and associated factors [17].

Charging Strategy	Factors
Coordinated	Optimise charging durations Optimise charging start-finish times Power demand stability
Smart	Lessens daily cost of electricity Reduces deviations in voltages Increase efficiency and reliability of distribution network
Delayed	Home charging increases owner energy bill
Off-peak	Reduces cost of charging through lower energy prices

An article looking at different charging period scenarios concluded with a smart charging method [20]. The methodology used for this study was based around mathematical formulas and load curves for driving, energy use and charging currents and voltages This method identified the most beneficial way to charge is by optimizing the start time and number of batteries that start charging at each time interval. With this optimization, the stochastic nature of individual driving patterns were considered to gain insight to realistic charging method.

2.3.1 EV Charging Impacts

A systematic study with a quantitative methodology considered the impacts of EV charging on the grid voltage stability. This was found to result in outcomes where negative impacts were likely to occur [21]. Another identified that fast charging stations may cause a significant reduction in the steady state voltage stability of the grid [22]. Another article investigating the impacts of EV on voltage stability found that charging loads could lead to negative impacts on system voltage stability [23]. The introduction of effective remedial measures was seen as a possible solution for reducing the impacts of EV on voltage system stability.

Within the realm of EV charging effects on voltage stability, one study explored the importance of spatial distribution in distribution networks [24]. It investigated two different suburban distribution networks in Australia to analyse the effects of voltage drops given different energy profiles for houses and EVs on a worst-case and best-case scenario basis.

The methodology used for this study was simple and effective. It used simulation software that ran the inputs over a 24-hour period. It collaborated data from battery specifications, housing energy profiles, network models and vehicle traffic to investigate the relationship between voltage stability and location of EV charger. Two networks were compared against one another to understand the effects of EV charging on voltage stability. The first network was a suburban residential network located in Melbourne and the second was a semi-rural residential network located in Townsville.

In a general sense, it was suggested that large EV loads would draw large amounts of current leading to drops in voltage in distribution networks. In addition to this, it was suggested that unbalanced phases could lead to increasing current in the neutral line resulting in voltage drops due to neutral line impedance.

It found that the charging of an EV at the weakest point in a distribution network had the same impact as charging 45 EV near the transformer. This in resulted in questions raised regarding the reliability of power for EV charging – should EV charging be reliable anywhere in a distribution network? It certainly raised this question in response to its results relating to impacts of EV charging and spatial location within the distribution network.

Relating this information to the effects of EV charging on strata distribution infrastructure suggests the location of a strata building within a distribution network could influence the impacts EV charging has on that network. Further questions arise when considering the switchboard infrastructure within strata buildings and what effects EV charging would potentially have.

Investigations into secondary transformer overloading, voltage drops and network demand were looked at in British Columbia for suburban, urban and rural distribution networks [25]. It used probabilistic load flow analysis based on Monte Carlo Simulation. This technique used multiple iterations of a probabilistic algorithm to output a set of values corresponding to unknown variables. In relation to transformer overloading, it was found that suburban transformers were subject to the highest amount of overloading. Urban area transformers however were found to undergo little overloading due to the design being three-phase and usually over compensating for demand in the specific urban locations.

Additionally, a study conducting an analysis for the impacts of EV on medium voltage distribution networks found that secondary transformers overloaded upon increased EV penetration [26]. It used a time series power flow approach with multiple inputs in linear relationship to determine the overloaded components shown below in figure 6.

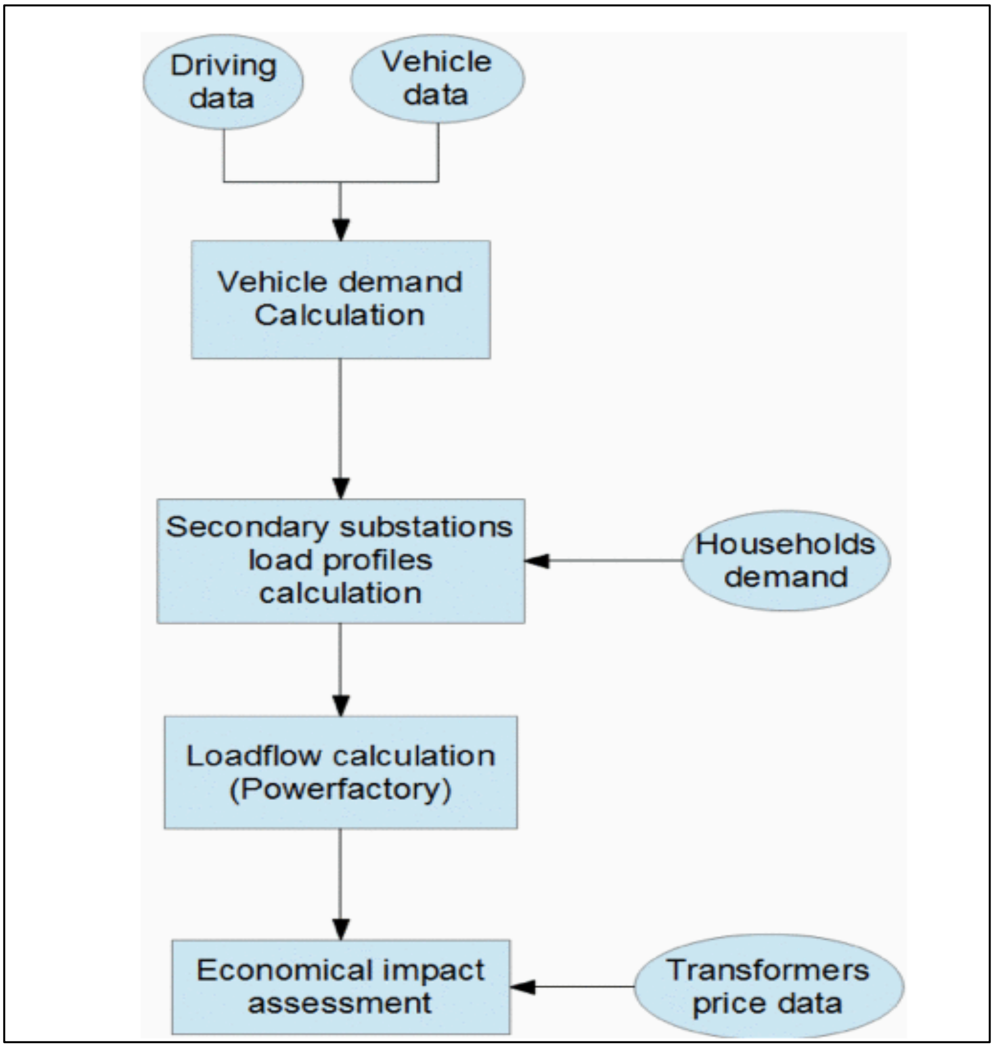

Figure 6. – Outline of data processing for time series power flow [26].

This flowchart can be comparable to the current research topic. In this model are inputs for EV data, building load demand and load profiles. A constraint of this flowchart model is that it doesn't consider charging factors. With this comparison, it could be suggested that a modification of this model could be applicable to the current research topic.

Similarly, a study looking at the impacts of EV charging on distribution networks showed negative outcomes upon large EV deployment in reference to the EV charging interface. In this study, voltage stability, phase imbalance and power quality were tested for. Significant findings were made relating to power quality as an outcome of non-linear converting devices within the charger. It showed that currents are susceptible to distortion and can be harmful to the grid. This issue becomes particularly significant with more EV charging on the grid [27]. What this indicates is another perspective to the issues EV charging could cause in distribution networks. Again the question relating to apartment building switchboards arises when considering the charging technology and associated grid impacts that could take place.

2.3.2 EV Charging in Residential buildings

An investigation of the impact of different charging strategies in large residential buildings was conducted in Belgium [28]. The investigation also focused on analyzing whether the introduction of a three-phase charger was needed.

It identified a number of relationships with EV charging concerning different charging periods and the associated effects through out the day as the focus based on a case study. For example, daytime charging decreases the simultaneous peak demand on the grid during nighttime periods and utilizes PV production. Due to the long standstill times of EV, it was acknowledged that charging at all possible locations should be encouraged utilizing the moments the car is parked. Again this is to help shave the peak demand for charging when the driver returns to their home. Lastly, the need to implement a three-phase charger was found to be unnecessary. Less than a tenth of the residential charging methods need power from a three-phase charger. It was found that a three-phase charger didn't improve the charging efficiency and only increased costs under installation.

An interesting point made in this particular work stated that peak shaving is attainable by using the onboard battery management system. This system only needs the time of next departure and present state of charge. Other considerations not looked at regarding this type of research are in terms of the maximum demand and the impacts three-phase charging could have on the building infrastructure and even the distribution infrastructure.

2.3.3 EV Costs

An investigation into EV deployment in urban areas was found. This study sought to understand the total cost of ownership based on real data as a comparison to CV. In summary this paper predicted that the cost of EVs is expected to reduce upon increase in sales as a result of buyer knowledge regarding EV benefits and government policy. The paper also includes research conducted relating to EV as a part of an integrated smart system [29].

2.3.4 EV Driving Patterns

A study conducted in Denmark sought to understand the driving patterns for EV integration into the grid [30]. The background for this study indicated that influences to the introduction of EV were traced back to enhancing renewable energy reliability with V2G system integration in the country. It highlighted that numerous other studies had pointed out that V2G integration could help the nation see its energy target of 50% wind power by 2025.

Using national survey data for transport, an analysis involving the driving distances and charging times was conducted. Using the statistical software SAS, results were found regarding the day with the highest driving distance and the average driving distance in Denmark. Denmark has shown similarities to Australia in its slow uptake of renewables and energy targets.

The importance of driving patterns for EV charging has been informative regarding the potential methods for this research topic. Limitations of this study however were pointed out saying that improvements could be made with using real data instead of surveyed data.

2.4 Renewables Integrated

A report was constructed by the CSIRO that proposed different energy scenarios for the future of Australia's energy system [31]. The integration of renewable generation, energy storage and EV, and how the cost payment scheme would function and affect customers were investigated through each scenario. It focuses on the electricity supply chain and the payment options. The significance of this report is that it shows insight to the probable realities that electricity consumers, public and private, will face. Furthermore, in presenting the different scenarios in table 4, combinations of each scenario are created which could also become the reality for Australia electricity supply.

This article affects and is directed at the future of energy consumers. Whether or not any of these scenarios will play out, all scenarios should be considered for all strata managers to enable them to become more proactive within their strata buildings energy efficiency.

Table 4. – Energy scenarios for the future.

Scenario	Description
Set and Forget	Central Control - Centralised power remains - Peak demand management adoption - Advanced metering and communications to enable flexibility for services - Large-appliance control, EV charge management, On-site storage
Rise of the Prosumer	Customer-centric - EV is popular - Cheaper renewables and storage tech - Centralised power becomes to expensive
Leaving the grid	Customer - Centric - Massive on-site generation and storage - EV is popular - Centralised power becomes to expensive
Renewable thrive	Central Control - Centralised power remains - Large scale adoption for renewable generation and onsite storage - Government – industry driven - Full renewable generation for future predictions

3 METHODOLOGY

While evaluating the current literature regarding the effects of EV charging on strata building power distribution infrastructure, it was identified that there is a significant area of material absent. From the current body of literature, there is a flow of knowledge regarding EV impacts on grid voltage stability, EV charging strategies, EV charging stations and EV impacts on distribution grids in residential areas. However, there is no literature that investigates the EV charging effects specifically on strata building power distribution infrastructure. This makes the importance of a research paper in this area more significant. Due to the lack of information in this area of literature, it is expected that this paper will be an exploratory project in finding key information relating to the research question.

3.1 Quantitative Methodology

Upon reviewing the current literature that surrounds the research question and the associated topics, a clear indication can be drawn from the type of methodology used in similar studies. It is suggested that due to the type of information that will be interpreted and also due to the sources of information being numerically based, a quantitative methodology will be best suited as seen in other studies.

Quantitative research has been carried out in various engineering areas and has been applied to associated topics regarding the research area. It is an approach that includes versatile measurements statistically and mathematically for further interpretation to be made. This method also provides a means for the data to be graphically illustrated accurately by the use of tables, charts and graphs where easier to understand.

3.2 Data Collection Structure

Methodologies from similar topics in comparison to the research question identified in the literature review were adopted for this research project. The methodology seen in figure 6 that uses a time series power flow model will be modified to suit the research topic. Modifications made to this model can be viewed below in figure 7. This model was selected due to the similarities between the inputs of the model and the desired outcomes. Through the adoption of relevant methodologies, it was expected that certain data would be required. This model will serve to structure the stream of collected data into a meaningful result.

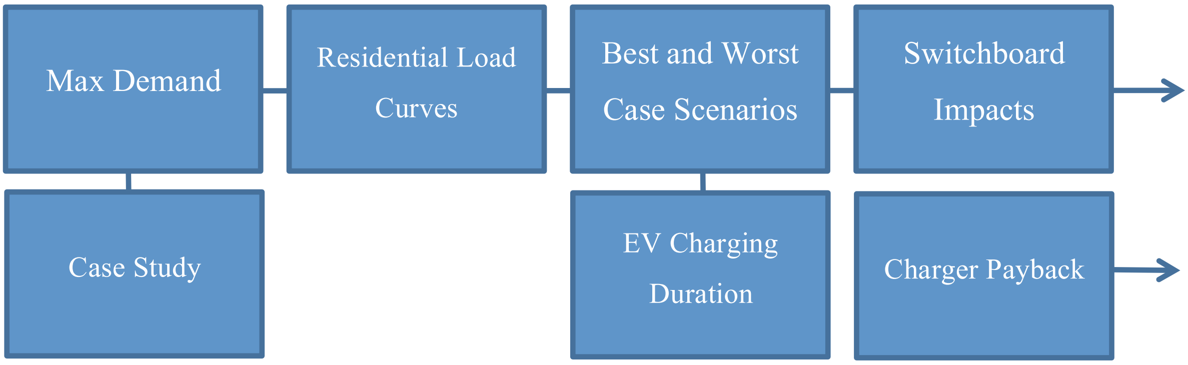

Figure 7. – Flow sequence for methodology

The proceeding sections outline the stages within the methodology. The first section, data collection explains what types of data are expected during the data collection process regarding the research topic. The second section justifies the methods of analysis used to manipulate the data collected into meaningful information.

3.2.1 Sampling

In accordance with other research methodologies identified in the literature review section, using sampling techniques for data collection was acknowledged [28]. It was perceived that sampling a case study be used to best model the impacts of EV charging on strata building switchboards. Gathering real data was expected to add to the credibility of any results. In addition to this it was also expected that peripheral issues found could still be relevant in other potential research projects within the research area in using case studies.

It was suggested that while conducting site assessments, the energy report assessment designed by WattBlock be used. The energy report recorded general building information like the number of levels and units, car-parking levels and lifts. It also took into consideration any recreational facilities like pools, spas or gyms whereby extra pumps would be installed. Other sections covered by the report relate to heating, ventilation and cooling, presence of any solar generation and storage, and lastly energy billing details. The energy report also contained a detailed lighting assessment segment that focused on common area lighting specifically the car-parking and fire staircases lighting.

As mentioned, part of the assessment was attaining the energy bills from the strata managers. This gave data regarding current energy consumption and how the pricing for energy was being applied.

3.2.2 Maximum Demand Calculation

Four ways of determining the maximum demand for strata buildings were identified. Of these four ways, it is suggested that through the method of calculation, the data attained from case studies can be used to understand the maximum demand for any building sampled.

As every building design is different, the electrical wiring and circuit arrangements are also expected to be different. Determining maximum demand by way of calculation is a way to find the buildings maximum circuit current supplied. It is also a method to understand the circuit arrangements necessary to protect the building and the supplying transformer from overloading. Using this method of calculation allows for phase balancing and cable rating selection for the main switchboard.

With this method it is suggested that even without physically measuring the supply cable rating, a solid idea of the buildings capacity can be attained by way of switchboard rating through maximum demand calculations. Disadvantages of this method however is that there can be considerable differences in the way a buildings electrical designs are actually made in contrast to the way that the calculation is done as the electrical equipment included in the calculations can be used in various different ways and times.

Regarding circuit arrangements for buildings, figure 8 shows the level of circuit protection for different areas of energy use by way of primary uses and sub-circuits. As seen below, safety service circuits such as, fire, evacuation and lifts are located at the top of the arrangement. This is a safety measure as no tripping of other circuits will shut these services off. It is demonstrated in figure 8 that the distribution switchboard is separated into groups of three single-phase systems where similar functions are grouped.

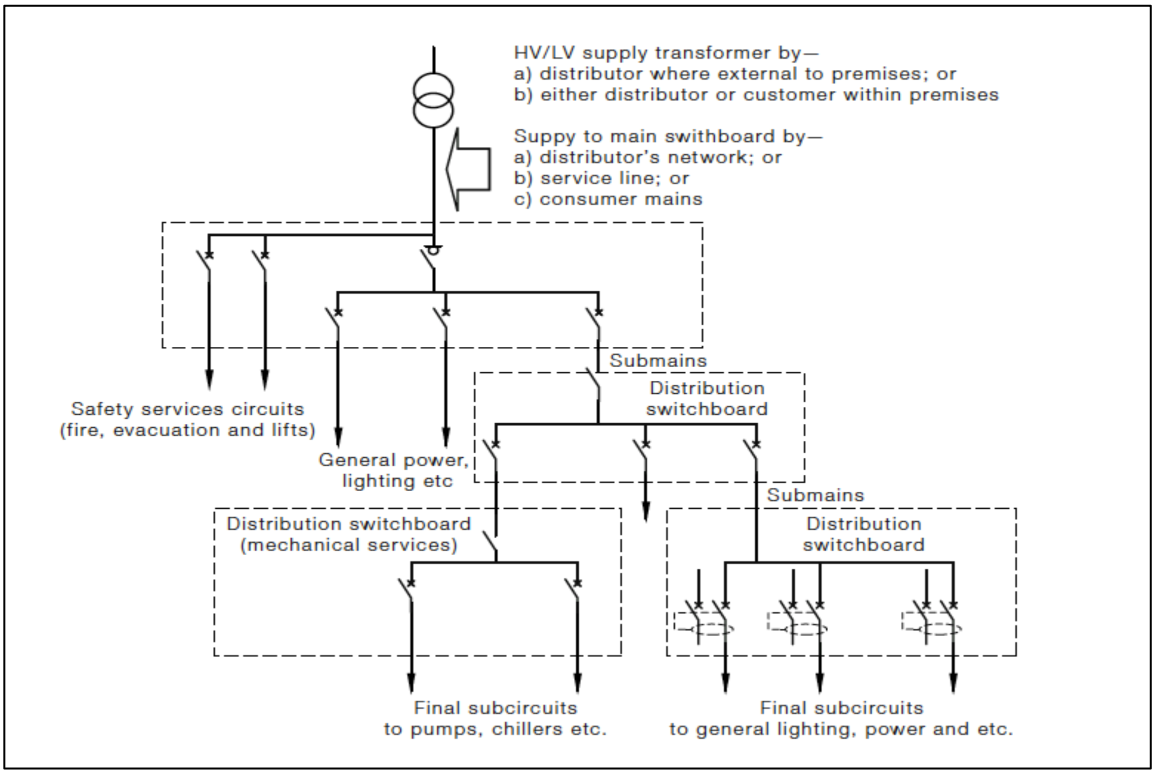

Figure 8. – Basic circuit arrangement schematic depicting mains supply and sub-circuits.

The models of EV that were most common in Australia were the Tesla Model S, the BMW i3 and the Nissan New Leaf. From these models, key specifications were noted and tabularised shown in table 5.

Table 5. – EV specifications for three selected models.

EV	Battery Capacity (kWh)	Battery Type	Driving Range (km)
Tesla Model S	75	Lithium Ion	370
BMW i3	18.8	Lithium Ion	312
Nissan New Leaf	30	Lithium Ion	172

The types of charging levels looked at within this research project are seen in table 6 below. The charge time were collaborated from EV charger suppliers and expressed in the range of the car replenished over time. The three levels, Level 2 (Trickle), Level 2a (Fast) and Level 3 (Rapid), are all based off the 230 V RMS grid system in Australia.

Table 6. – Typical charging rates for EV.

	Current (A)	Rating	Charge Rate
Level 2	16	240 V 3.3 kW	18 – 40 km/hour
Level 2 Fast	30	240 V 6.6 kW	45 – 140 km/hour
Level 3	40	DC Fast Charger	420 km/hour

3.3 EV Charging Impacts On Switchboards

Assessing EV charging impacts on the switchboard was executed by implementing different charging levels while increasing the number of EV being charged at the same time. It is expected that upon increasing the number of EV charging simultaneously on one common phase, there is potential for the phase to overload. To further look into these impacts, charging levels 2, 2a and 3 will be implemented. This will be conducted at best and worse times for each phase determined by the times of lowest and highest demand. As each phase was calculated to be slightly different while load balancing different electrical equipment, it was suggested that it was necessary to see which functions would be affected from switchboard impacts.

3.3.1 Case Study

A Brisbane strata building was used as a case study for this project. It was necessary to use a case study to attain real data for further analysis and interpretation. The case study was selected at random out of three choices in which energy audit related questions were posed to gain data.

The case study building contained a total of 45 apartments over 5 residential floors from the ground up. The building also accounted for one underground parking level and a ground level visitor car park. On ground level was also a gym facility for tenants to use at their own leisure. This level also contained the switchboards for the entire building. The building contained a single lift and two fire stairs.

3.3.2 EV Impact Assessment Model

The following section explains the process for maximum demand calculation of the case study. In this process are the assumptions made, the equations used and the related ruling in accordance to AS3000 standards. Finding the maximum demand for a buildings circuit arrangements gives a better idea on the capacity of the switchboard. By determining the cable ratings for switchboards, it is expected that the amount of available capacity for EV charging can be found and from there the impacts of EV charging on the switchboard.

3.3.3 Electrical Equipment Ratings

Common electrical equipment was recorded from the case studies switchboard labels. In table 7 viewed below, the electric ratings for the electrical equipment identified were noted for load balancing onto each phase by use of nameplate ratings from images of the equipment from site assessments and typical ratings presented by AS3000.

Table 7. – Electrical equipment ratings for communal areas.

Communal area	Count	Rating	Unit
Lighting	165	100	W
Socket outlets	6	10	A
Lift motors	1	12	kW
Hot Water pump	1	1.2	kW
Tank Power	1	1.2	kW
Exhaust Fan Power	1	1.1	kW
Roller Door	1	300	W
Hydrant Pump Power	1	1.2	kW

As most equipment is expressed in units of power the equation 1 displayed below was used to get obtain the current ratings.

$$\frac{Power\ Rating\ (W)}{230\ V} = Equipement\ Current\ (A) \tag{1}$$

Load balancing is a vital part of building circuit arrangements as unbalanced loads on each phase can result in negative effects for the building and the grid. Table 8 below shows the preliminary step how each of the electrical equipment shown above is balanced across each phase evenly. Note that this table is used to work out the current loading on each phase shown in table 9.

Table 8. – Load balancing on each phase for electrical equipment.

Phase arrangement	Red	White	Blue
Lighting	55	55	55
Socket outlets	2	2	2
Lift motors	1		
Hot Water pump			1
Tank Power			1
Exhaust Fan Power		1	
Roller Door			1
Hydrant Pump Power			1

Table 9. – Heaviest load at maximum demand

	Column Rules	Red (A)	White (A)	Blue (A)
Lighting	A	17.93	17.93	17.93
Socket outlets	B(i)		13.04	
Lift motors	E(i)	27.50		
Hot Water pump	D			5.22
Tank Power	D			5.22
Exhaust Fan Power	D		4.78	
Roller Door	D			1.30
Hydrant Pump Power	D			5.22
Total		45.43	35.76	34.89

For column rules viewed in Table 9 please refer to appendix A. In this table the total demand for each phase can be viewed as well as the heaviest loaded phase. Once each load was as evenly balanced as possible the cable parameters were then selected based on the maximum demand for each phase. The cable selection presented in table 10 is a simple display of cable parameters that shows important information for this study.

Table 10. – Basic cable selection guide for single-phase applications [9].

Cross-sectional area (mm^2)	Protective Rating (A)	
	In Air	In Ground
10	50	63
16	63	80
25	80	100

It assumed for this case that the cable connecting to each phase will have a maximum rating of 80 Amps in compliance with safety standards presented in AS3000. This assumption is based purely off of the standards presented in AS3000. This assumption could create three scenarios in terms of accuracy of results being; 1) the cable rating is too high, 2) the cable rating is too low or 3) the cable rating is suitable in a real application. The first and second scenarios will mean that the following results are presenting a version that will ultimately mean EV impacts are lesser or greater on switchboards.

3.3.4 Energy Bills

Energy bills were utilized to provide the amount of power used on average per day. This information was then used to understand the amount of current drawn on average per hour shown in table 11. The calculation is show in equation (2) below where the average daily usage is divided by time and then rms voltage to yield the current drawn.

$$Current\ Drawn\ (A) = \frac{Average\ Daily\ Usage\ (kWh) \times 1000}{Time\ (hours)} \div 230\ V \qquad (2)$$

Table 11. – Average current drawn calculated from energy bills

Quarter	Average daily usage (kWh)	Current drawn (A)
Q1	196.71	35.64
Q2	195.48	35.41
Q3	199.67	36.17
Q4	193.92	35.13
	Average current per day	35.59

Calculations to find the demand curve for case study one was done using the average current found from the energy bills as a scalar quantity to find the positioning for the load curve given the demand curve for Queensland in the literature review section in figure 1. What was produced is shown in figure 9.

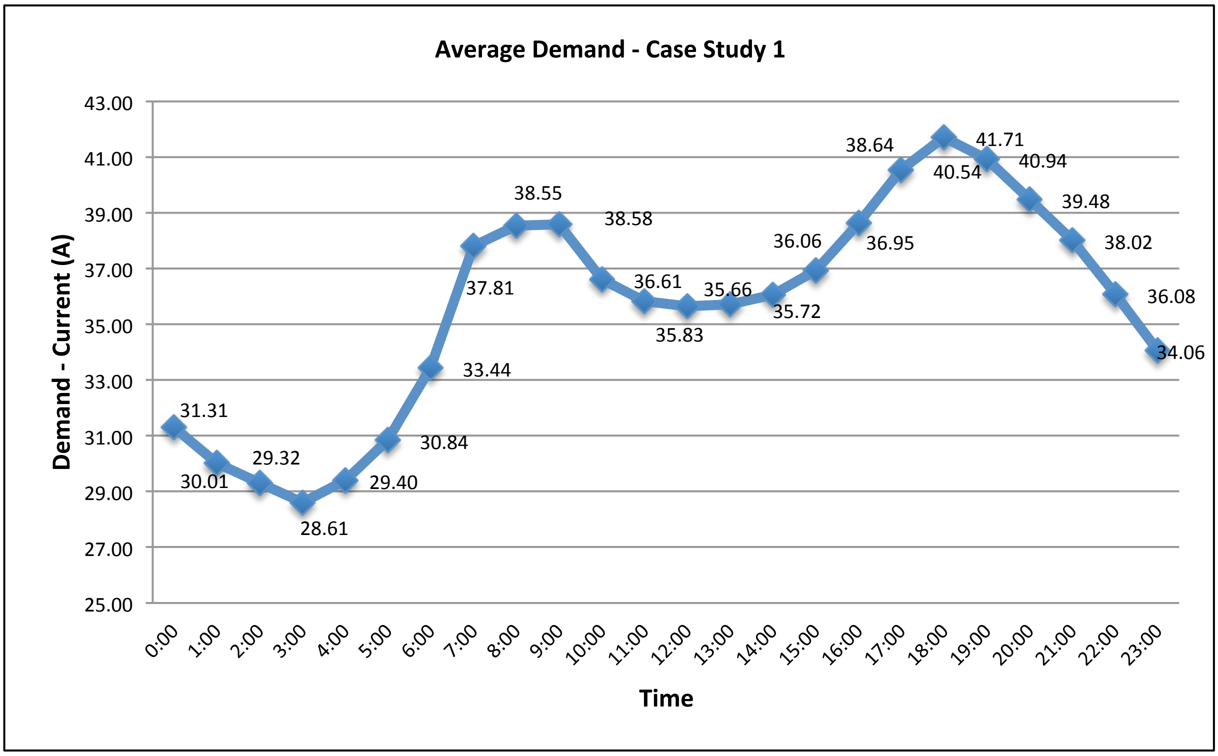

Figure 9. – Hypothetical average demand curve for Case Study 1.

The times considered for this research project were chosen in terms of best and worst times in relation to current demand. From figure 9 the best and worst times respectively are at 3:00 am and 6:00 pm dictated by lowest and highest current demand. To simulate a decent charge

The last stage in this process was modeling a demand curve given the data collected. Demand curves for each phase are shown in figure 10. This was calculated by dividing the average for Queensland demand figures recorded by the cable ratings calculated for maximum demand. This would then return a scalar quantity to divide the demand figures at each hour to result in the demand per phase at that same hour. Equations (3) and equations (4) demonstrate this.

$$Scalar = \frac{Queensland\ Demand\ Average}{Max\ Demand} \quad (3)$$

$$Demand\ per\ Phase = \frac{Queensland\ Demand\ (each\ hour)}{Scalar} \quad (4)$$

This information was graphically represented for plausibility and to identify relative best and worse times for charging as a preliminary expectations during analysis.

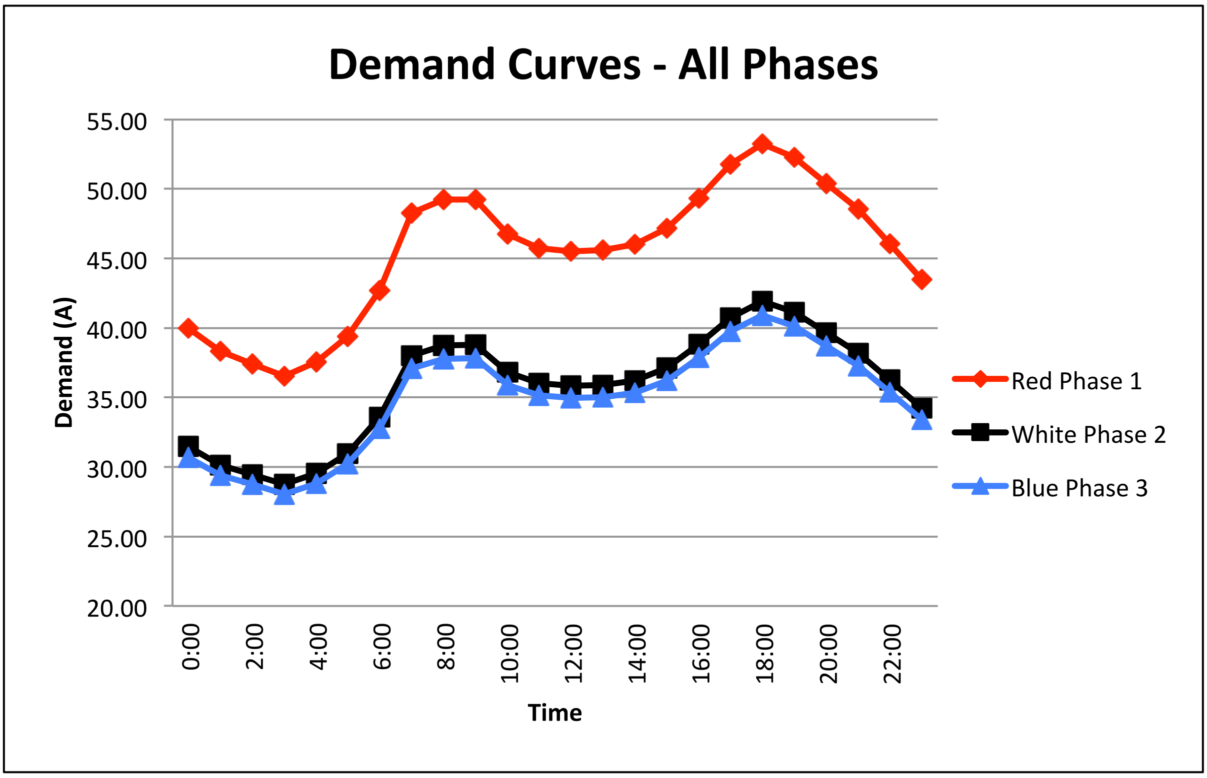

Figure 10. – Load curves over 24 hour period for all three phases.

From this point equation (5) was used to model the sum of the charger current demand and base demand for each EV charging at any point in time.

$$I_{EV} \; = \; I(t)_P + EV(n) \times I_C \qquad (5)$$

Where I_{EV} is the Total current demand during charging, $I(t)_P$ is the phase current at time t , *EV(n)* is the number of EV charging and I_C is rated charger current.

3.3.5 EV Charging Duration

To calculate the charge duration for each EV, equation (6) displayed below was used. This equation took the EV range (D_{EV}) expressed in kilometers and charge level speed (U_c) expressed in kilometers charged per hour as inputs.

$T_C = \frac{D_{EV}}{U_C}$, where T_C is the charging duration expressed in hours. (6)

Given this equation, it is expected that a simple comparison of charging durations for each charging level can be expressed. Aligning with the current methodologies, the best and worst case scenarios are expected. This is due to the range that charging level speeds are expressed in from the slowest to fastest rate at which a charging level provides.

It is not realistic to assume that each charger only functions at the best or worse speeds. However, it does provide a benchmark when conducting charging assessments. It is expected that the EV with larger batteries will benefit most from level 3 rapid charging and be affected the most by level 2 trickle charging. It is also expected that the difference in charging duration between all EV at level 3 charging speeds will be insignificant.

3.3.6 Charger Payback Period

Charger payback period was calculated using the total investment cost divided by the annual cash flow shown in Equation (7).

$$Payback\ Period\ (Years) = \frac{Investment\ Cost\ (\$)}{Annual\ Cash\ Flow (\$)} \quad (7)$$

Total investment cost consisted of capital cost and installation price. Price flow was calculated by comparing the annual fuel cost to a popular combustion engine vehicle fuel cost. The selected vehicle for this was a Mazda 3. It was expected that this calculation would provide the payback period for an EV charger under the three EV selected. The charger costs were gathered from an Australia charging supplier called JETcharge.

4 RESULTS ANALYSIS

Firstly the typical non-working charging hours are displayed at Level 2 trickle rate charge speed per phase. This result was simulated across a 12-hour period from 6:00 pm to 6:00 am. This presented a more realistic outcome for EV charging in strata buildings. The graph considers the maximum number of EV before reaching the cable capacity of 80 amps.

The best and worst case scenarios per phase at each charge level has been included. These results present the number of EV able to be charged before exceeding the cable capacity for the switchboard for each phase at all charge levels. These graphs express the most likely times at which exceeding the demand for cable capacity will occur and for the number of EV that this will happen for under the assessed conditions.

The total number of EV per phase able to be charged at each level is provided for best and worst cases respectively. This presents the safest amount of EV able to be charged per phase at each charging level in a simpler format in comparison to the demand curves.

EV charging duration times for each EV has been presented comparing each charge level in the best and worst case scenarios. It is expected that by using the information regarding charging duration, the demand per phase can be observed across the charging duration for each EV.

Given capital costs for and installation costs EV chargers, a payback period was calculated. This was done using the difference in annual fuel costs of running a combustion engine vehicle. The Mazda 3 was selected at random out of the top 20 vehicles sold in Australia sourced from the Green Vehicle Guide.

4.1 Typical Non-Working Charging hours

Figure 11 presented below demonstrates a typical approach to EV charging in respect to the time of charging. Unsurprisingly, charging on phase 1 exceeds cable capacity as the heaviest loaded phase, during peak times. However charging two EV on the other two phases at the same time does not exceed cable capacity.

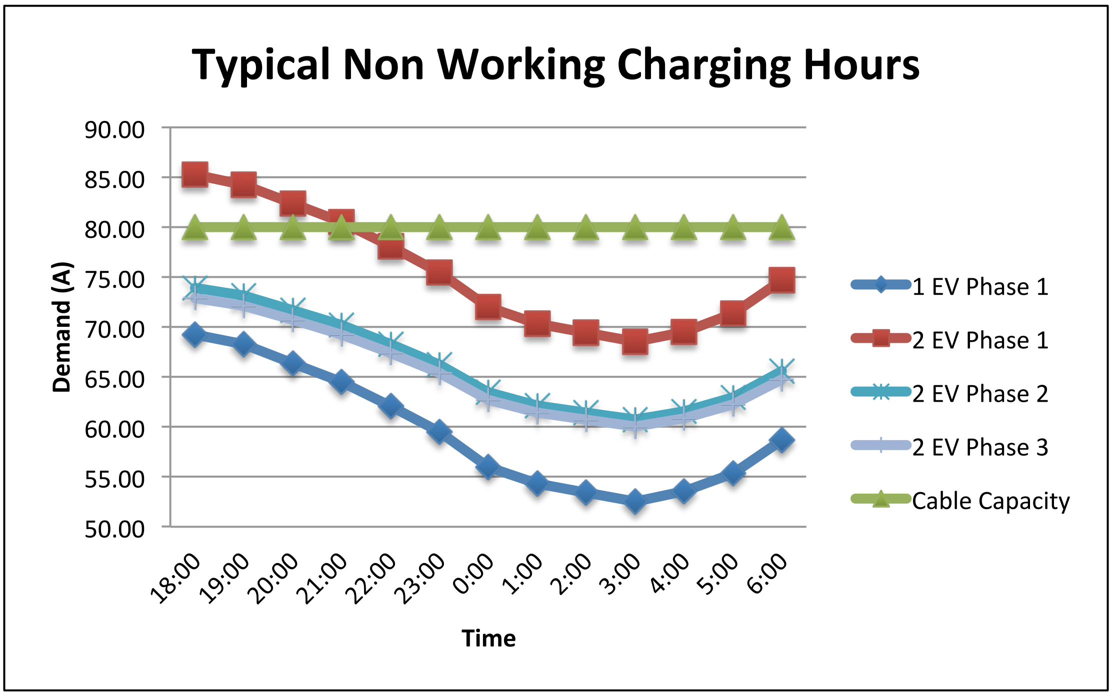

Figure 11. – Non-working charging hours using level 2 charging speed.

4.2 EV Charging Impacts On Switchboards

Figures in this section were constructed to highlight the demand EV charging would have on each phase. As each phase carried different loads for the model distribution network in the case study building, it was assumed that different functions would be directly impacted when a phase becomes overloaded. This is likely to occur when the demand for the number of EV charging becomes greater than the cable capacity. The results for this section are presented in best-case scenario then worst-case scenario for all charging levels.

4.2.1 Best Case Scenario

At trickle charge rate in Phase 1, it can be seen in Figure 12 that charging three EV will exceed the cable capacity. For the lighter loaded Phase 2 and Phase 3, only at 6 am and after do the charging levels exceed demand.

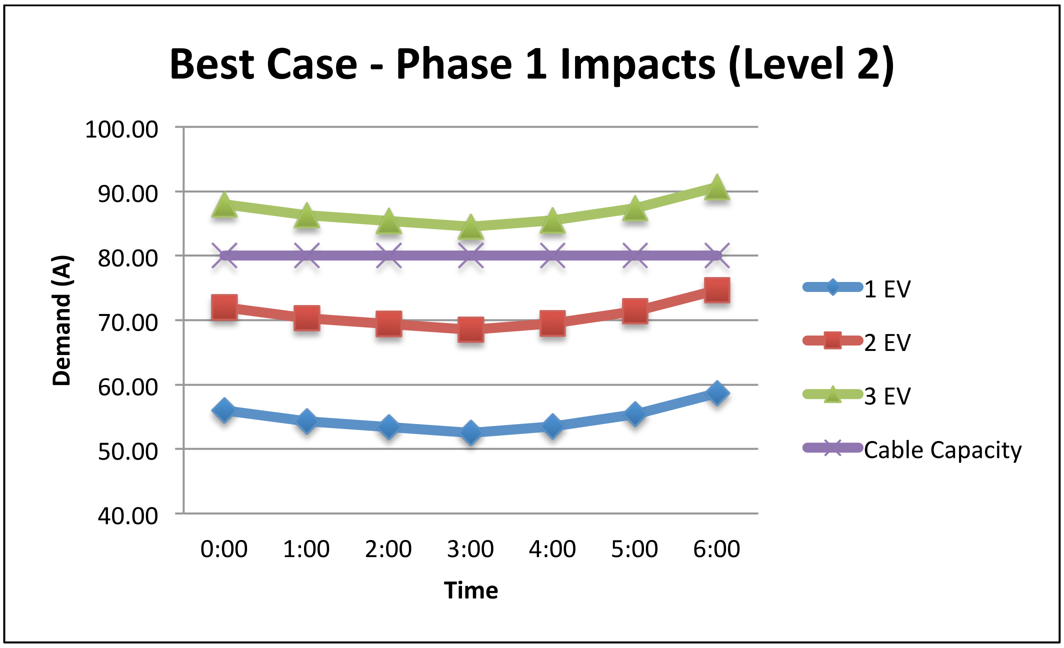

Figure 12. – Level 2, 16 A charging speed on heaviest loaded phase (Phase 1).

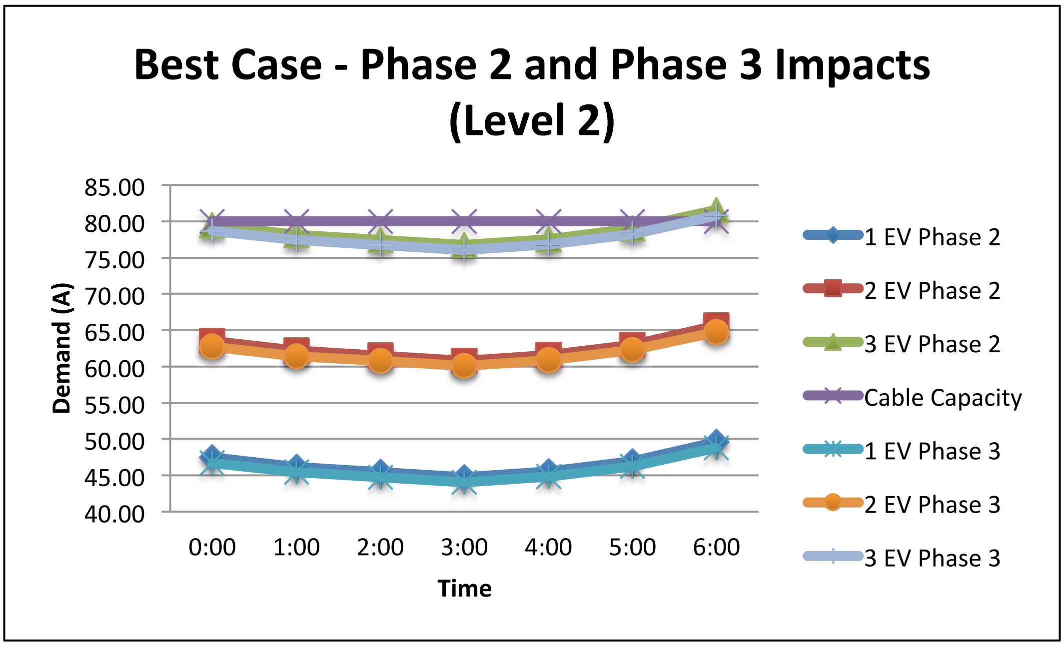

Figure 13. – Level 2, 16 A charging speed on other two phases.

It can be observed in Figure 13 that under the assessed conditions, a total of 3 EVs can be charged on each phase before 6 am. Breaching this limit would cause trigger the safety protection devices for each associated phase.

Fast charging at 30 A per phase resulted in only one EV able to be charged at anytime. Two EV were assessed to see the excessive demand each EV added viewed in figure 14.

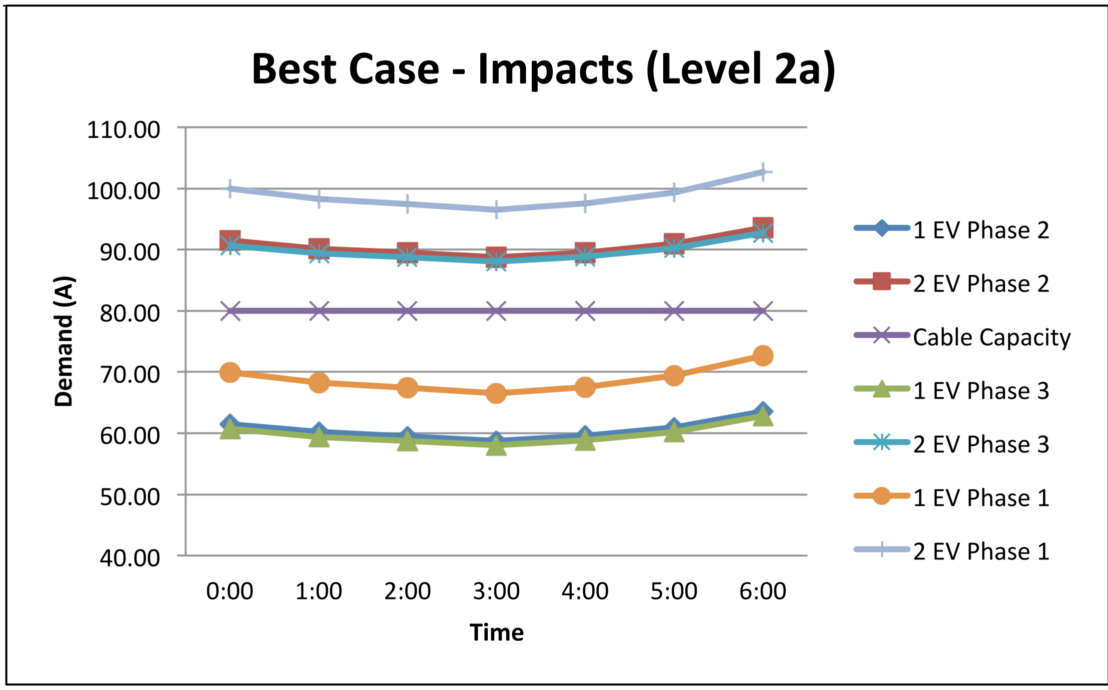

Figure 14. – Level 2a, 30 A charging speed on all phases.

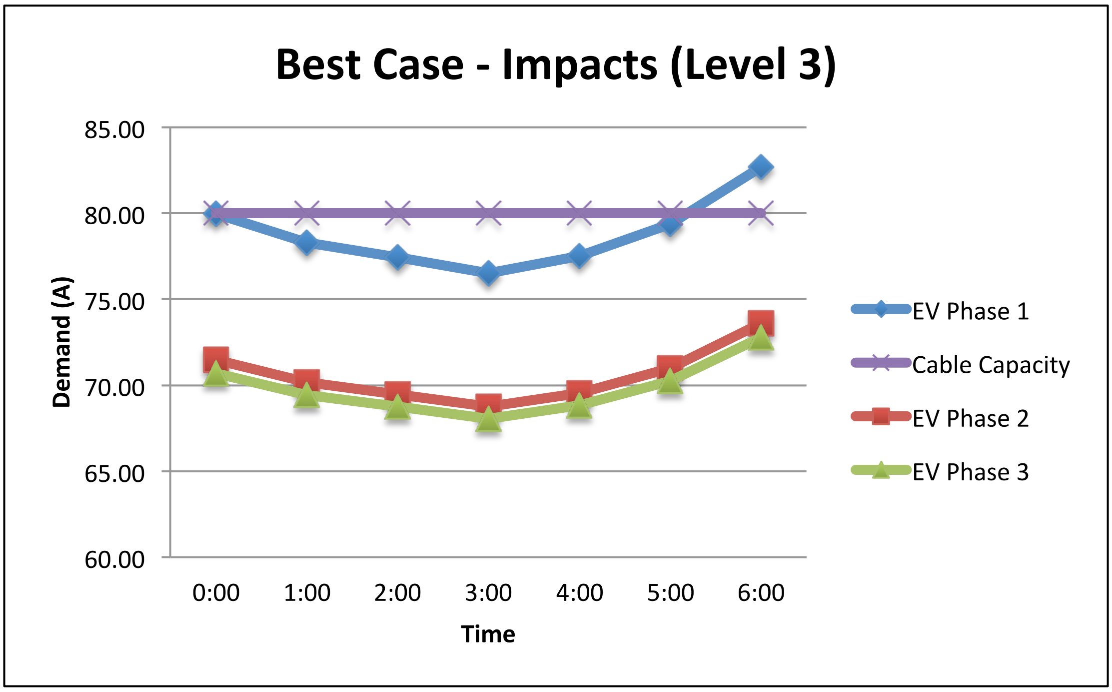

Figure 15. – Level 3, 40 A charging speed on all phases.

While evaluating charging at Level 3 speeds shown in figure 15 the heaviest loaded phase exceeds the cable capacity at 6:00 am. Charging at this speed before midnight also exceeds the cable capacity for Phase 1 and is assumed to affect functions placed on this phase.

4.2.2 Worst Case Scenario

Assessed during the times of peak demand, it can be seen that the numbers of EV that exceed the cable capacity are greater. To prevent overloading observed in figure 16, demand management could be implemented. Safely charging two EV shown in figure 17 is the result produced for assessing the impacts on Phase 2 and Phase 3.

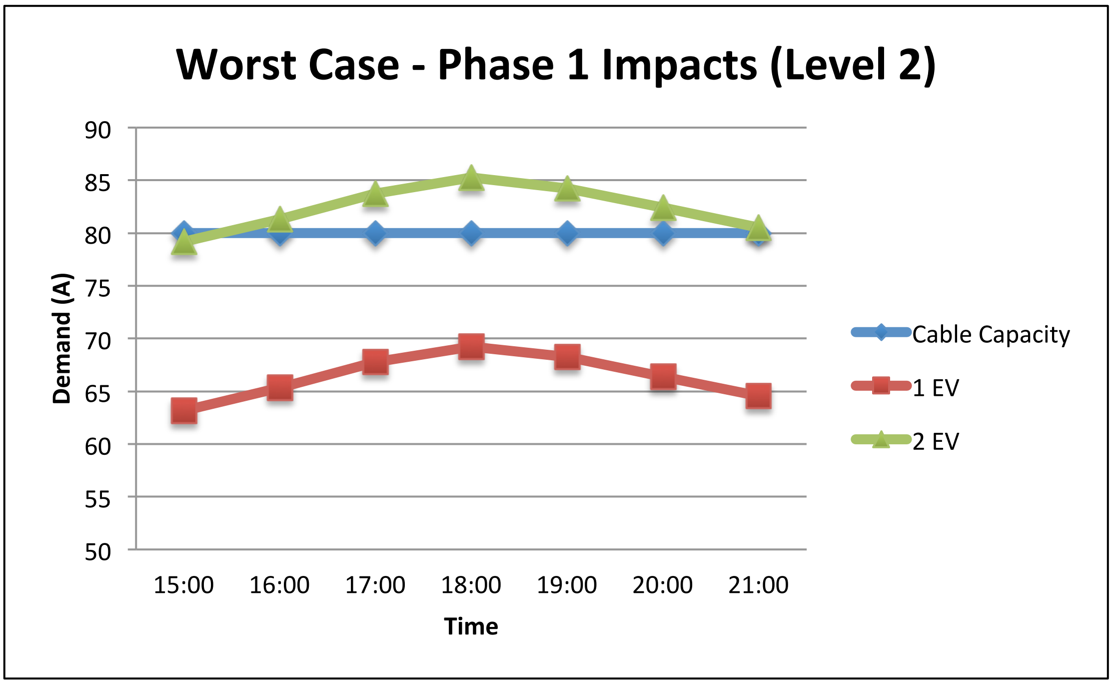

Figure 16. – Level 2, 16 A charging speed on all phases.

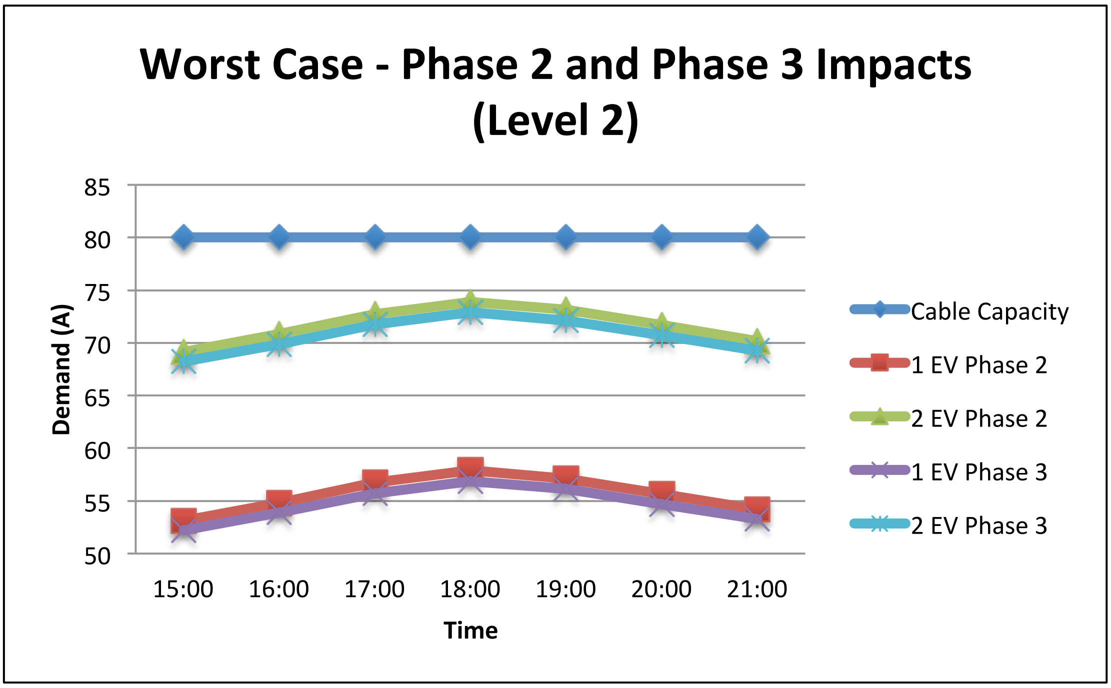

Figure 17. – Level 2, 16 A charging speed on phases 2 and 3.

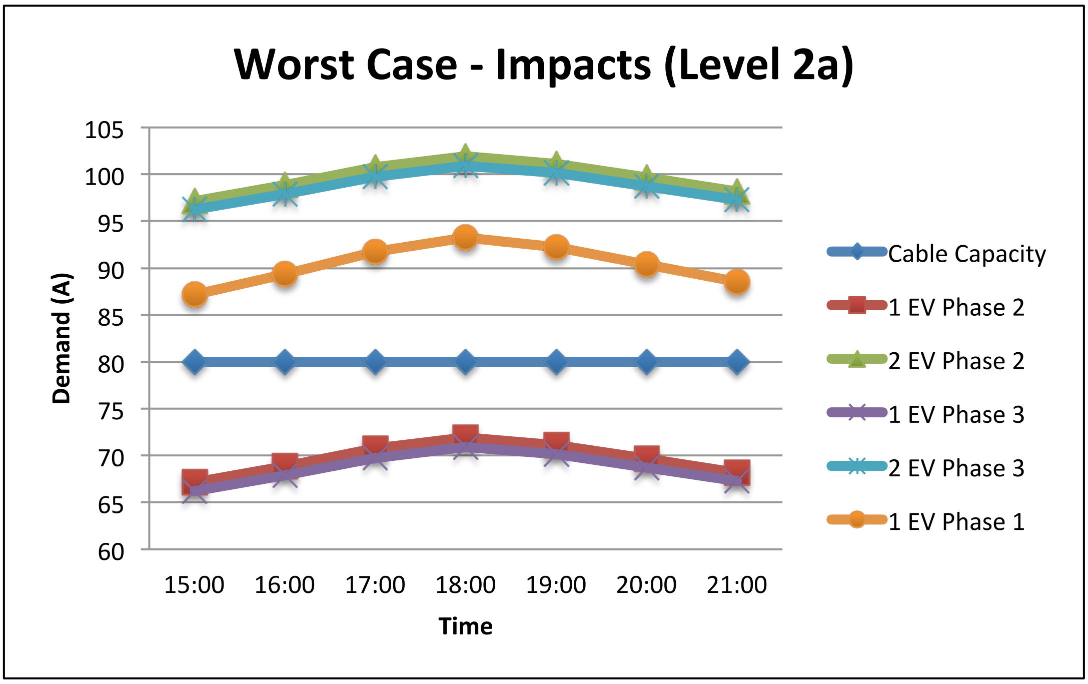

Figure 18. – Level 2a, 30 A charging speed on all phases.

Figure 18 shows that charging at level 2a causes overloading on all phases. As the heaviest loaded phase, phase 1 is unable to charge any EV at the worst-case scenario time. A possible solution for this could be either charge at a lower rate or delay charging until demand has decreased.

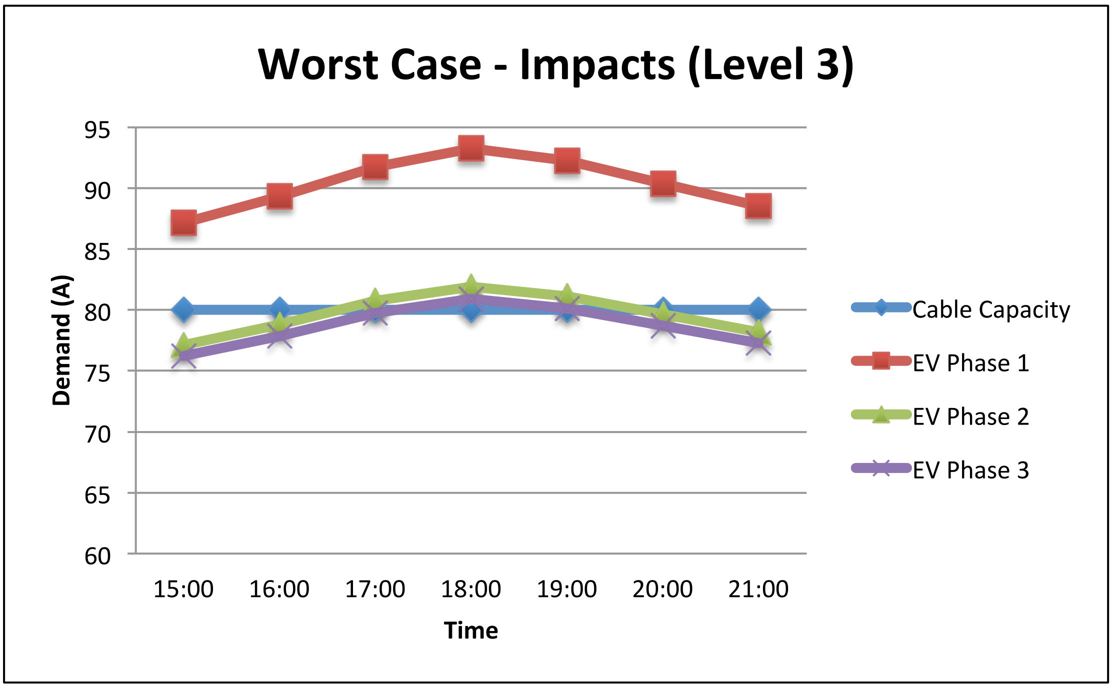

Figure 19. – Level 3, 40 A charging speed on all phases.

At peak times it is seen that charging at level 3 speeds is undesirable due to the demand for charging exceeding cable capacity. It is expected that charging management be implemented to prevent situations such as this or if unable to do this, then a system upgrade. The lighter loaded phases 2 and 3 are viewed to exceed the cable capacity at the peak time for demand and no other time for charging a single EV. This can be taken into consideration in terms of charging management.

4.3 EV Charge Duration Impacts

The resulting charging duration for each EV at each level can be viewed below in figure 20. These durations can be used to observe the demand times throughout charging periods. The usefulness of this data is grasped in the context of charging management. The difference between all three EV at level 3 charging is minimal due to the expected range of charge used in contributing calculations

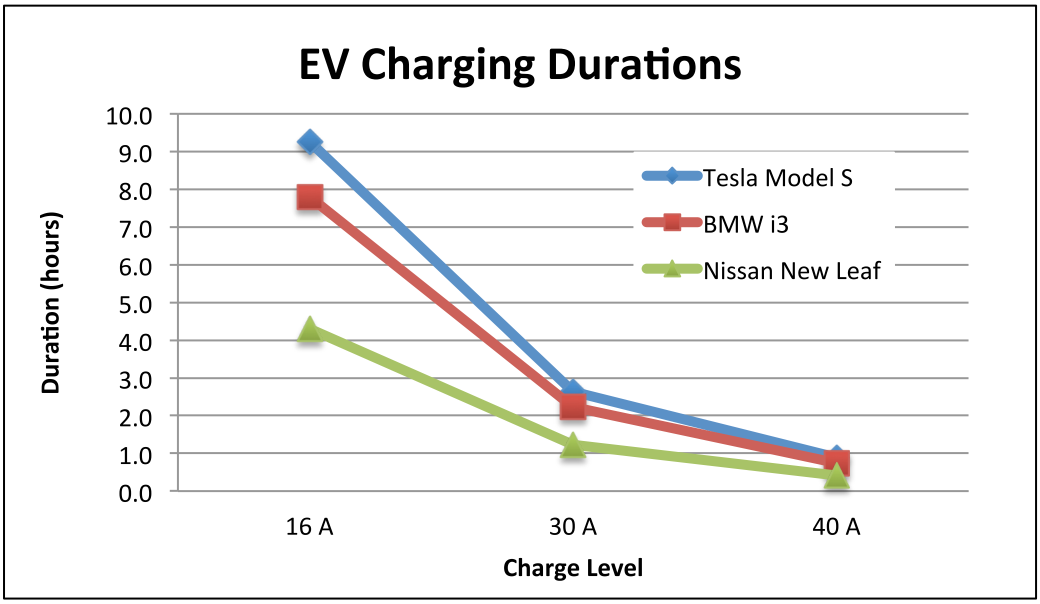

Figure 20. – Charging durations for each level of charging.

4.4 Charger Payback Period

EV charger payback periods were assessed with the selected three EV. Figure 21 displays the fastest payback period for BMW i3. Payback was calculated using the difference in annual fuel costs as annual cash flows. The total investment costs for each EV charger, inclusive of installation costs, show quite a fast payback within an estimated 3-year period. It is suspected that maintenance costs for chargers are negligible as they are not likely to change.

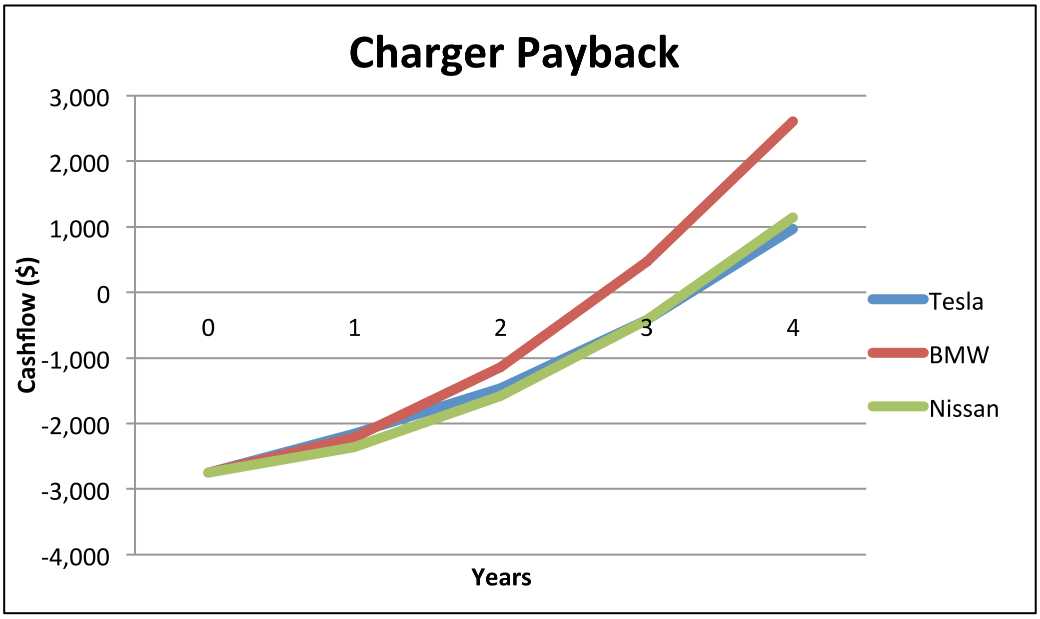

Figure 21. – Payback period of EV chargers approximating savings verse CV.

5 DISCUSSION

As an exploratory project, evaluating the results found was done in absence of directly related literature. As reviewed in the literature, the impacts of EV charging on distribution networks are seen to have negative consequences. In certain cases, EV charging was found to impact voltage stability, power quality, transformer overloading and power reliability. It was suggested that drawing parallels from the current literature could be applied to EV charging impacts on strata building switchboards.

5.1 Switchboard Impacts

Switchboard overloading triggers circuit breakers to activate. Overloading through exceeding cable capacity was identified in three different situations; by charging too many EV on the same phase at once, charging EV on higher charging levels than needed and charging during peak times. In conducting EV charging assessments at the best and worst times in terms of charging time of day, it was found that charging management be implemented to avoid overloading. By gaining an understanding of what causes overloading, insights into what services will be affected can also be understood. In alignment with the methodology used for this study, phase 1 carried the lift demand and thus overloading this phase would mean lift failure.

The highest number of EV (appendix B) able to be charged in the best-case scenario is 6 with two cars per phase at level 2 speed, 16 A. This would be during non-working hours starting after the peak demand period. Using level 3 charging speed in the best-case scenario and incorporating results shown in figure 3.11, identifies that the charging duration would last less than an hour and have little impact on the switchboard if executed correctly. Apart from this EV charging is most impactful on charge rate level 3.

Solutions for exceeding cable capacity and other limitations regarding circuit protection come in various forms. One of the most effective ways found was through reducing the current demand of a building to free capacity to go towards charging. Reducing the consumption of common services and functions like 24-hour lighting could have major influences on EV charging impacts. Three other ways identified to contribute to reducing switchboard overloading are receiving a system upgrade, demand management or renewable generation and storage.

5.2 EV charging durations

Comparing charging durations for each EV at different charging levels with EV demand per phase at best and worse times helps to assess the impacts caused for charging at any time. This also presents a way to approach charging management. Given that any of the assessed vehicles needs to be charged from any battery level, using the demand profiles for the number of EV charging at once can provide a picture of the charging level appropriate – and vice versa. Although not completely accurate, this also serves as a simple guide for EV of similar battery size.

The concept of charging management can also be applied to demand management. This can be interpreted through combining the results found from phase demand with different charging levels at different times. In knowing the electrical equipment and functions distributed on each phase in a buildings circuit design can help towards charging management. However, this is likely not to be the case with other strata buildings due to uniqueness of electrical distribution designs, especially in newer buildings that most likely include allocations for future electrical equipment implementation. How EV charging can be implemented into strata building distribution infrastructure safely and effectively presents another area to look at for future research.

5.3 EV Charger Payback Period

Payback periods identified for EV chargers were convincing. Differentiated between CV and EV annual fuel costs, the payback for an EV was observed to be between 2 – 3 years. Understanding the payback period benefits of EV charging can encourage EV uptake in strata buildings and promotion for future tenants and current tenants.

6 CONCLUSION

The impacts of EV charging on strata building distribution infrastructure were investigated. Impacts such as phase overloading caused by excessive demand on cable capacity properties were investigated using the Tesla Model S, BMW i3 and the Nissan New Leaf. When applying three charging speeds (level 2 trickle, level 2a fast and level 3 rapid) at best and worst-case scenario times, overloading was observed on each phase. The result of exceeding cable capacities was consequential switchboard impacts.

Using the method of calculation to determine the maximum demand for a case study building, the loading on each phase distributed from the switchboard was found. Allocating appropriate cable sizes by knowing phase loads was conducted to model the distribution infrastructure for the case study building. Applying averages to energy bills received from the case study buildings to scale average state residential energy demand down provided an energy demand curve fitted to the case study consumption. Using this in conjunction with the modeled maximum demand allowed EV charging scenarios to be implemented.

Impacts caused by exceeding cable capacity were caused in three main ways; charging too many EV on single a phase, using a higher charging level than necessary and charging during peak times. Impacts of EV charging were also indicative of the potential harm on services loaded onto the same phase. Services placed on each phase are vulnerable to failure upon overloading in the case of the previously mentioned EV charging impacts.

Using EV charging durations for different levels of charging were identified to be helpful towards charge management. Understanding the duration needed for charging during any part of the day was useful in identifying what level of charging would be most suitable. Combining the charging duration, charging demand profiles and charging level gives a clear picture on the possible impacts likely to occur for many charging scenarios.

Modeling the payback period for EV chargers was calculated to take 2 – 3 years. As an uptake factor in knowing the payback costs for EV chargers is very low, the forecasts for EV implementation into strata buildings will be likely. Given these payback figures, the impacts identified previously gain more significant value.

Information constructed during this research project can be applied to other projects in similar areas of topic. It is suggested that a more accurate means for modeling strata building energy demand and distribution infrastructure be done for more precise results. Understanding impacts on switchboard from EV charging can be observed throughout this work

6.1 Future Work

Although there have been various research papers contributed to the impacts of EV charging on distribution networks and the grid, there was a considerable gap in the knowledge regarding EV charging in strata buildings. Future topics for research regarding this area are plentiful. The impacts associated with EV charging in strata buildings have only been briefly investigated in this work.

Through conducting this research it was found that there are a considerable amount of issues that need to be addressed in relation to EV charging and also more generally EV driving in strata buildings. An important issue related to EV charging in strata buildings is in reference to where the supply is connected to for each charger. Although enabling the tenant to connect their individual charger to their apartment circuit would be easier in terms metering and billing the energy use, is it possible with the limited cable capacity for the apartment? The question would then go to what functions within the apartment would fail under charging conditions. If chargers were connected to common property switchboards, how would metering and billing be done for each EV charger? Would strata buildings allow for EV charging for visitor cap-parks?

Regarding the by-laws for EV charging, questions arise related to the process for tenants to request EV chargers. In terms of installing chargers, is this done at each tenants cap-park space or will there be a set of common chargers with a pay-per-charge metering system? Keeping in mind some car-parks are multi-level and would present challenges with installing cables through levels and at far distances from switchboards and again who would the costs be issued to? Issues relating to driverless EV by-laws also remain currently unexplored.

These questions offer future work in respect to EV charging in strata buildings. Although not necessarily aligned in the same engineering discipline as this work, the issues interweave into factors that impact the distribution infrastructure of strata buildings.

7 REFERENCES

[1] Department of Environmental and Energy, "Australia's 2030 Climate Change Target", 2015.

[2] Department of Environment and Energy, "Quarterly Update of Australia's National Greenhouse Gas Inventory: June 2016", 2016.

[3] "What is Strata? - SCA - Strata Community Australia", Strata Community Association, 2017. [Online]. Available: https://www.strata.community/understandingstrata/what-is-strata. [Accessed: 14- Apr- 2017].

[4] Australian Bureau of Statistics, "Building Approvals By Type of Buildings", 2016.

[5] Australian Bureau of Statistics, "B32 Tenure Type and Landlord Type by Dwelling Structure", 2011.

[6] D. Suh and S. Chang, "A Heuristic Rule-Based Passive Design Decision Model for Reducing Heating Energy Consumption of Korean Apartment Buildings," *Energies,* vol. 7, pp. 6897-6929, 2014.

[7] Y. Yıldız and Z. D. Arsan, "Identification of the building parameters that influence heating and cooling energy loads for apartment buildings in hot-humid climates," *Energy,* vol. 36, pp. 4287-4296, 2011.

[8] D. Biekša *et al*, "Energy Efficiency Challenges in Multi-Apartment Building Renovation in Lithuania," *Journal of Civil Engineering and Management,* vol. 17, pp. 467-475, 2011.

[9] Electrical installations (known as the Australian/New Zealand wiring rules) /[prepared by Joint Technical Committee EL-001, Wiring Rules], 5th ed. Sydney, NSW: Standards Australia, 2007.

[10] "Australian Energy Market Operator", Australian Energy Market Operator, 2017. [Online]. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Data/Metering/Load-Profiles. [Accessed: 28- May- 2017].

[11] Department Of Industry, Innovation and Science, "Australian Energy Update", Canberra, 2016.

[12] Australian Bureau of Statistics, "Australia Social Trends 2013", Canberra, 2013.

[13] Australian Bureau of Statistics, "Motor Vehicle Census, Australia, 31 Jan 2015", Canberra, 2015.

[14] Australian Energy Market Operator, "Electric Vehicles", 2016.

[15] National Transport Commission, "Carbon Dioxide Emissions Intensity for New Australian Light Vehicles 2015", 2016.

[16] Manjunath, Archana, and George Gross. "Towards a Meaningful Metric for the Quantification of GHG Emissions of Electric Vehicles (EVs)." *Energy Policy*, vol. 102, 2017, pp. 423-429, doi:10.1016/j.enpol.2016.12.003.

[17] Ferreira, João C., et al. "Smart electric vehicle charging system." *Intelligent Vehicles Symposium (IV), 2011 IEEE*. IEEE, 2011.

[18] T. Ustun, A. Zayegh and C. Ozansoy, "Electric Vehicle Potential in Australia: Its Impact on Smartgrids", EEE Ind. Electron. Mag., vol. 7, no. 4, pp. 15-25, 2013.

[19] Cao, Y, Tang, S, Li, C, Zhang, P, Tan, Y, Zhang, Z & Li, J 2012, 'An Optimized EV Charging Model Considering TOU Price and SOC Curve', IEEE Transactions on Smart Grid, vol. 3, no. 1, pp. 388-393.

[20] Qian, Kejun, et al. "Modeling of load demand due to EV battery charging in distribution systems." *IEEE Transactions on Power Systems* 26.2 (2011): 802-810.

[21] Dharmakeerthi, C. H., N. Mithulananthan, and T. K. Saha. "A Comprehensive Planning Framework for Electric Vehicle Charging Infrastructure Deployment in the Power Grid with Enhanced Voltage Stability." *International Transactions on Electrical Energy Systems*, vol. 25, no. 6, 2015, pp. 1022-1040, doi:10.1002/etep.1886.

[22] Dharmakeerthi, CH, Mithulananthan, N & Saha, TK 2014, 'Impact of electric vehicle fast charging on power system voltage stability', *International Journal of Electrical Power & Energy Systems,* vol. 57, pp. 241-249.

[23] C. Dharmakeerthi and N. Mithulananthan, "PEV load and its impact on static voltage stability", Plug-In Electric Vehicles in Smart Grids: Integration Techniques, vol. 91, pp. 221-248, 2015.

[24] J. de Hoog *et al*, "The importance of spatial distribution when analysing the impact of electric vehicles on voltage stability in distribution networks," *Energy Systems,* vol. 6, pp. 63-84, 2015.

[25] L. Kelly, A. Rowe and P. Wild. Analyzing the impacts of plug-in electric vehicles on distribution networks in british columbia. 2009, . DOI: 10.1109/EPEC.2009.5420904.

[26] Qiuwei Wu, Yi Ding, Seung Tae Cha, Ostergaard, J., Nielsen, A.H. Impact and cost evaluation of electric vehicle integration on medium voltage distribution networks. *Innovative*

Smart Grid Technologies (ISGT Europe), 2011 2nd IEEE PES International Conference and Exhibition on, pp. 1-7, 2011

[27] G. A. Putrus *et al*. Impact of electric vehicles on power distribution networks. 2009, . DOI: 10.1109/VPPC.2009.5289760.

[28] Van Roy, Juan, et al. "Apartment Building Electricity System Impact of Operational Electric Vehicle Charging Strategies." *IEEE Transactions on Sustainable Energy*, vol. 5, no. 1, 2014;2013;, pp. 264-272, doi:10.1109/TSTE.2013.2281463.

[29] Nanaki, EA, Xydis, GA & Koroneos, CJ 2016, 'Electric vehicle deployment in urban areas', *Indoor and Built Environment,* vol. 25, no. 7, pp. 1065-1074.

[30] Q. Wu *et al*. Driving pattern analysis for electric vehicle (EV) grid integration study. 2010, . DOI: 10.1109/ISGTEUROPE.2010.5751581.

[31] CSIRO, "The Future Grid Forum's analysis of Australia's potential electricity pathways to 2050", 2013.

APPENDICES

Appendix A

Column rules used for determining load balancing in methodology section were extracted from the table shown below.

359 **AS/NZS 3000:2007**

TABLE C2
MAXIMUM DEMAND–NON-DOMESTIC ELECTRICAL INSTALLATIONS

1	2	3
Load group	**Residential institutions, hotels, boarding houses, hospitals, accommodation houses, motels[a]**	**Factories, shops, stores, offices, business premises, schools and churches[a]**
A. Lighting other than in load group F[b,c]	75% connected load	Full connected load
B. (i) Socket-outlets not exceeding 10 A other than those in B(ii)[c,e]	1000 W for first outlet plus 400 W for each additional outlet	1000 W for first outlet plus 750 W for each additional outlet
(ii) Socket-outlets not exceeding 10 A in buildings or portions of buildings provided with permanently installed heating or cooling equipment or both[c,d,e]	1000 W for first socket-outlet, plus 100 W for each additional outlet	
(iii) Socket-outlets exceeding 10 A[c,e]	Full current rating of highest rated socket-outlet, plus 50% of full current rating of remainder	Full current rating of highest rated socket-outlet plus, 75% of full current rating of remainder
C. Appliances for cooking, heating and cooling, including instantaneous water heaters, but not appliances included in groups D and J below	Full connected load of highest rated appliance, plus 50% of full load of remainder	Full connected load of highest rated appliance, plus 75% of full load of remainder
D. Motors other than in E and F below	Full load of highest rated motor, plus 50% of full load of remainder	Full load of highest rated motor, plus 75% of full load of second highest rated motor, plus 50% of full load of remainder
E. Lifts	(i) Largest lift motor–125% full load (ii) Next largest lift motor–75% full load (iii) Remaining lift motors–50% full load For the purpose of this load group, the full-load current of a lift motor shall mean the current taken from the supply when lifting maximum rated load at maximum rated speed	
F. Fuel dispensing units	(i) Motors: First motor–full load Second motor–50% full load Additional motors–25% full load (ii) Lighting–full connected load	

(continued)

AS/NZS 3000:2007 360

TABLE C2 (*continued*)

1	2	3
Load group	**Residential institutions, hotels, boarding houses, hospitals, accommodation houses, motels**[a]	**Factories, shops, stores, offices, business premises, schools and churches**[a]
G. Swimming pools, spas, saunas, thermal storage heaters including water heaters, space heaters, and similar arrangements	Full-load current	
H. Welding machines	In accordance with Paragraph C2.5.2, taking into account power factor correction	
J. X-ray equipment	50% of the full load of the largest X-ray unit, additional units being ignored	
K. Other equipment not covered by load groups above	By assessment	

NOTES:

[a] See Clause 1.6.3 for where the maximum demand for consumers mains, submains, and final subcircuits, respectively, may be determined by assessment, measurement or limitation.

[b] In the calculation of the connected load, the following ratings shall be assigned to lighting:

(i) *Incandescent lamps* 60 W or the actual wattage of the lamp to be installed, whichever is the greater, except that if the design of the luminaire associated with the lampholder permits only lamps of less than 60 W to be inserted in any lampholder, the connected load of that lampholder shall be the wattage of the highest rated lamp which may be accommodated. For multi-lamp luminaires, the load for each lampholder shall be assessed on the above basis.

(ii) *Fluorescent and other discharge lamps* Full connected load, i.e. the actual current consumed by the lighting arrangement, having regard to auxiliary equipment, such as ballasts and capacitors.

(iii) *Lighting tracks* 0.5 A/m per phase of track or the actual connected load, whichever is the greater.

[c] A socket-outlet installed more than 2.3 m above a floor for the connection of a luminaire may be included as a lighting point in load group A.

An appliance rated at not more than 150 W, which is permanently connected, or connected by means of a socket-outlet installed more than 2.3 m above a floor, may be included as a lighting point in load group A.

[d] Load group B (ii) applies to an electrical installation, or portion of an electrical installation, incorporating permanently installed heating and/or cooling equipment specifically provided to render unnecessary the use of socket-outlets for portable electric space heating or cooling appliances. Whether heating or cooling or both is deemed necessary to avoid the use of portable heating or cooling equipment will depend on the location and climate involved.

[e] For the purpose of determining maximum demand, a multiple combination socket-outlet shall be regarded as the same number of points as the number of integral socket-outlets in the combination.

Appendix B

Total number of EV able to be charged on all 3 phases under the same level of charging rate for best and worst case.