Electric Vehicle Charging – Impact Review for Multi-User Residential Buildings in British Columbia

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1 Executive Summary

Early steps in shifting the energy delivery means for urban automotive transportation from fossil fuels to electricity have encountered somewhat unexpected obstacles in the case of charging infrastructure installations in multiple unit residential buildings (MURBs). In these buildings, unfamiliarity on the part of the general public with electricity and electric vehicle technology combined with numerous strata governance and installation cost issues have combined to slow the rate of electric vehicle charging installations despite available incentives.

The amount of power required for electric vehicle charging can create significant effects within building electrical distribution systems depending on the level of implementation planned. Present regulations mandate that each electric vehicle (EV) charging circuit must be considered as a full, continuous electrical load for the purposes of designing electrical wiring and equipment. For a level 2 charging circuit (6.6 kW), this translates into an electrical load larger than a standard residential clothes dryer which must be treated as if it is always in use for each circuit of this type installed.

Making provisions for EV charging in new MURB designs can be achieved technically by the building design community. This is now in progress and is motivated largely due to changes to City of Vancouver building regulations that came into force in 2011. However, if the planned number and type of vehicles to use EV circuits does not materialize as new MURBs become occupied, then these provisions will result in unused building electrical distribution system infrastructure and attendant sunk costs.

Adding EV charging in existing MURBs is much more challenging and expensive than for new construction projects. Retrofitting for significant levels of new EV loads will result in a lack of electrical capacity in the lower portions of building distribution systems first and create the need for electrical equipment upgrades. In smaller MURBs, provision for significant amounts of EV charging will have relatively more impact and the effects may be felt higher up the distribution system towards the service entrance.

Regulations governing how EV loads must be accounted for in B.C. building electrical designs will likely be modified with more widespread EV adoption as demand control features are integrated into building control systems. In the near term, basic demand control systems can control individual EV chargers in an on/off manner but eventually, smart grid technology will allow building control systems or outside agencies to control the chargers for all connected EVs to most efficiently use the available building electrical capacity while still providing satisfactory recharging performance for EV owners.

2 Introduction

The motivations and constraints that affect the adoption rate of electric vehicles are complex and multi-faceted. Motivations for adoption of passenger type EVs range from social concerns over energy security, sustainability and climate change to anticipated operating cost benefits and even to basic consumerism. Constraints on adoption of passenger type EVs range from relatively higher vehicle costs, lack of charging infrastructure and concerns over future EV maintenance issues such as battery life and battery replacement [1].

This report will focus on the subset of the vehicle charging constraint that applies specifically to EV charging implementation within multi-unit residential buildings. These buildings are of interest because:

1) The majority of passenger EV charging will logically occur when a vehicle is stationary. For most passenger vehicles, the longest stationary time period is at overnight at a residence.
2) Due to the population demographics of British Columbia, a relatively high proportion of potential EV adopters are in the urban and suburban metro Vancouver and southern Vancouver Island areas. In these areas, MURBs represent points of population concentration and, for many locations not adequately served by rapid transit, a significant concentration of commuter vehicles.

Recent initiatives by government agencies designed to promote EV adoption by incentivizing charging infrastructure equipment and installations have encountered some obstacles when dealing with MURBs. In researching this report, interactions with MURB stakeholders have highlighted a mix of technical and non-technical issues which combine to complicate EV charging infrastructure installation. This is not surprising considering that, for most of the public, EV's are an emerging technology and, as such, are not well understood. North American society has over 100 years of experience with internal combustion engine (ICE) vehicles and, although few people have a deep understanding of the technology, most drivers are competent users with very deep attachments to the convenience and freedom afforded by their passenger vehicles. In recent years however, an increasing number of people have become concerned with the undesirable side effects of fossil fuel combustion.

In a similar manner, it’s reasonable to state that the general public also has only a user level knowledge of electricity but very little knowledge of the complex systems that produce and deliver it. In absolute numbers, almost none of the public have knowledge of the building electrical power systems which form a direct, in-line component of the complex system which makes energy generated hundreds of kilometers away available for local use.

MURBs that consider implementation of EV charging on more than a trivial scale put their decision makers (often a strata council) in the position of needing to understand emerging vehicle technology in the context of their particular building electrical design constraints plus their strata governance issues. Given varying levels of technical knowledge of volunteers found on a typical strata council and the fact that money must be spent in common areas for installation, it is not surprising that there can be confusion and hesitancy on the part of MURB decision makers in deciding when, and to what degree, to act on requests for EV charging in their buildings.

The objectives of this report are to collate the background information necessary for stakeholders to appreciate the potential impacts of EV charging on present and future MURB electrical designs. This will be done by:

1) Providing the relevant background on EV technology which drives the basic design and costs of the building electrical systems upstream of the EV connection point.
2) Providing an overview of the relevant regulations which govern the electrical impact of EV charging in MURBs.
3) Providing a summary of major stakeholder viewpoints on provision of EV infrastructure in MURBs.

4) Providing a description of how building electrical designs are affected by EV implementations presently and illustrations of how EV charging provisions are being included.
5) Illustrating probable electrical effects on building electrical systems when retrofitting a MURB for increasing amounts of EV charging.
6) Reviewing how future changes in regulation and the evolution of technology will modify the impact of large scale EV charging on MURB electrical systems.
7) Making recommendations to stakeholders regarding actions which can improve the implementation efficiency for future EV charging in MURBs.

Information for this report was assembled by conducting on-site inspections of existing MURB facilities and new buildings currently under construction, interviews with equipment suppliers, building contractors, utility and consulting industry professionals and EV interest groups plus technical literature reviews.

3 Electric Vehicles in British Columbia

3.1 Context

Vancouver, and Canada's, first recognizable gas station was opened in 1907 [2] by Imperial Oil downtown at the intersection of Smythe and Cambie streets. The facility consisted of a 59 litre tank and hose system with an attendant present during the day. The new gas "station" was undoubtedly recognized by operators of the seven or eight gasoline powered automobiles then on the roads in Vancouver as a significant improvement over the previous system which had early adopters of gasoline powered vehicles paying to use the local sawmills gasoline supply by dipping buckets into wooden gasoline barrels and then filling their vehicle tanks.

During the first decades of the 20^{th} century gasoline, electric and steam energy technologies were competing to replace the horse in personal transportation uses, particularly in urban settings. At this time, many of the public in British Columbia's population centers of Victoria, Vancouver and New Westminster were already familiar with the uses of electricity for transportation from streetcar systems which had operated since the early 1890s [3]. During this period, a number of successful, and by all accounts relatively easy to operate, electric vehicles were available for purchase in major cities. However, by the end of the First World War, the steam and electric vehicle technologies had been defeated by the internal combustion engine (ICE) technology using gasoline as a fuel.

Liquid fossil fuel systems continued to evolve due to high energy density, ease of transport and their inherent energy storage capability. They quickly came to dominate as the primary source of energy for transportation (mobile) applications.

Electricity, because of the emergence of AC (alternating current) technology over DC (direct current) technology during the same time period, evolved to be produced at large facilities then transmitted and used for most stationary applications where grid infrastructure could economically be built. Where suited, electricity was also used for fixed route transportation applications such as the streetcar systems mentioned.

This division of duties between these two forms of energy, by and large, has been sustained to the present. Attempts have been made in the intervening years to use stored electricity for flexible mobile transportation but it is only within the past decade that advances in power electronics, computer controls and battery technologies have combined with increased social concerns to position electric vehicles as an increasingly viable commercial alternative to ICE vehicles.

3.2 Overview

Planning for the potential impact of large scale EV adoption within British Columbia has been underway for a number of years at various levels of government and crown corporations. The amount of energy projected by B.C. Hydro to support EV adoption is sufficiently large that the province's integrated electric utility has included EV planning in its load forecasting reports since 2010 [4]. Table A.4.1 of B.C. Hydro's 2012 Integrated Resource plan separates residential EV growth from commercial EV energy growth. The annual energy projection for residential EV charging begins at 1 GWh for 2013 and rises to over 1,757 GWh in 2032. The values for commercial EV (electric truck) load growth are an additional 33% on top of the residential energy projections.

By 2032, the additional power required to support residential and commercial EV charging is projected as 451 MW. For perspective, 451 MW is approximately 40% of the final capacity of the Site C dam and approximately 3-4% of B.C. Hydro's planned 2032 generation capacity.

3.3 Light Duty Vehicle Pool Size

Government data for British Columbia shows that there are approximately 2,300,000 light duty vehicles (LDVs) registered in the province [5]. For initial EV adoption, the pool size is reduced by removing rural locations and most pickup trucks for practical reasons including type of vehicle use (power requirements) and longer distances travelled as compared to urban dwellers. After these adjustments, the results still shows that the 70% of the light duty vehicle pool which could be replaced by EVs in B.C. is located in the metro Vancouver and southern Vancouver Island regions. These two regions combined are only 1% of B.C.'s land area but constitute the focal point of this report.

3.4 EV Adoption and Implementation Projections

The electrification of a significant portion of B.C.'s eligible pool of LDVs is of value to the provincial government in achieving its overall greenhouse gas emissions reduction targets. To that end, the provincial government via the LiveSmart BC MURB Incentive Program had offered up an 80% rebate on level 2 charging systems earlier in 2013 and continues to offer EV point of sale rebates per vehicle and to subsidize single family dwelling EV charging infrastructure [6].

4 Electricity for EVs - An Energy System View

For the purposes of illustration, Figure 1 shows the major electrical energy system components involved in the delivery of energy to an EV battery in B.C.

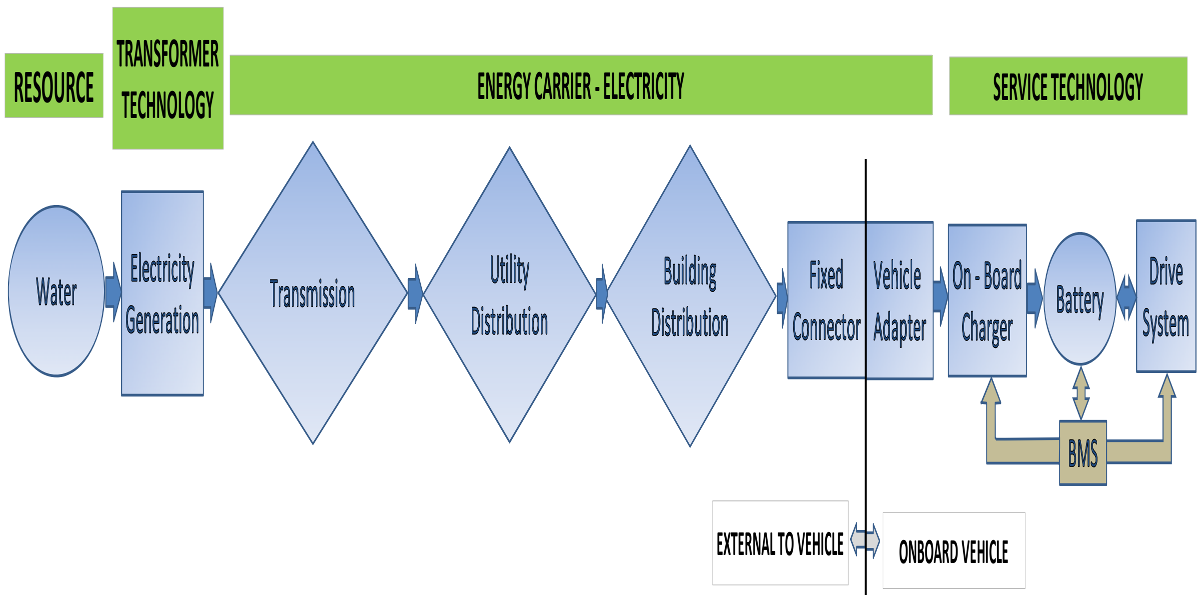


Figure 1 – Electricity Delivery System Block Diagram

The *resource* indicated in Figure 1 is the potential energy of water contained behind dams and, more recently and to a smaller degree, the energy of water in motion in run of river type projects.

The *technology* that *transforms* the kinetic energy of water consists of a variety of turbine types and close coupled electrical generators. The turbines convert the water's kinetic energy into mechanical energy which, in turn, is converted to electrical energy in the generators.

The *energy* produced is *carried* at high voltage levels to all points of use via an extensive *transmission* system within the province. The bulk of electrical energy within British Columbia is generated in the north-central portions of the province for use in the relatively heavily populated south-west of the province – the lower Fraser valley and southern Vancouver Island.

At major load centers, the transmission voltages are reduced and the electrical energy becomes part of the local *utility distribution* system which provides connections to local facilities such as commercial, institutional and residential buildings.

Inside each building is a series of electrical energy carrying components (meters, equipment, wire, protection devices) that collectively are referred to as the *building distribution* system. It is the purpose of the building distribution system to transmit electrical energy in a safe and efficient manner to its point of end use.

At each EV charging location there is some form of a *fixed* connection point, often combined with a cord and male *connector*, which makes contact with the *plug adaptor* on the EV. (The acronym for this equipment is EVSE for Electric Vehicle Service Equipment.)

When this connection is made correctly, electrical energy becomes available to the vehicles *on-board charger* under control of the vehicles battery management system (BMS). The charger converts the incoming alternating current (AC) electricity to the direct current (DC) voltage level required by the battery under BMS control. The vehicle *battery* is then charged and the energy is stored for use by the EV *drive system* and vehicle auxiliary loads.

The scope of this report is the *building distribution* portion of the energy carrier path in Figure 1. This is the part of the energy system where complex EV related questions that cannot be answered by the EV manufacturer's representatives or by the electrical utility are encountered. To understand the multi-faceted nature of these questions a review of several topics outlined in the balance of this report is required.

5 EV Types and Charging Systems

5.1 EV Types

Electric LDV models are continuing to be developed and brought to market by traditional automotive manufacturers and new electric vehicle only companies. Some EVs, such as the Nissan Leaf, have been commercially available for several years. Others, such as the Ford Focus EV, are becoming available in this model year while other major automakers such as BMW are announcing models for the near future. As the adoption of electric vehicles grows, the segmentation of the EV market will continue by the same automotive metrics that apply to the ICE vehicle market – features, performance, economy and cost.

Two broad types of LDVs with electrical grid connections are commercially available. First are plug-in hybrid (PHEV) electric vehicles (e.g. Toyota Prius, Chevrolet Volt) which also have an internal combustion engine for extended range or power duty. The second is battery (BEV) electric vehicles (e.g. Nissan Leaf, Tesla S) which depend entirely on energy provided externally that is then stored in the vehicle battery for use.

The main functional differences between PHEVs and BEVs is that the battery capacity must necessarily be larger in BEVs to achieve reasonable operating ranges as there is no energy source other than what can be stored on board to provide the driving range. This difference in battery size and the electric operation range between PHEVs and BEVs can easily be seen from

Figure 2 where the PHEVs have smaller batteries and much lower electric only driving ranges than BEVs.

Vehicle	Type	Battery Capacity (kwh) /Type	Electric Range (km)	On board charger (KW)	AC Contact Charging	DC Contact Charging	Wireless Charging
Chevy Volt	PHEV	16.5 / Lithium Ion	61	3.3	J1772 AC Level 1,2	No	Optional - Plugless Power 3.3 KW Max
Toyota Prius Plug in	PHEV	4.4 / Lithium Ion	22	2.9 (Est)	120 or 240 volt	N/A	-
Ford Focus	BEV	23 / Lithium Ion	153	6.6	J1772 AC Level 1,2	?	-
Nissan Leaf	BEV	24 / Lithium Ion	117	6.6	120 volt or 240 volts	Yes -SV and SL. 30 min to 80%	Optional - Plugless Power 3.3 KW Max
Mitsubishi I - Miev	BEV	16 / Lithium Ion	100	3.6	8A@120 VAC or 15A@240	30 min to 80%	-
Tesla S	BEV	60 or 85 / Lithium Ion	335/426	10 or 20	J1772 AC Level 1, 2	No	-

Figure 2 – Sample Commercial EV Characteristics

5.2 EV Battery Charging Systems

The time to charge any battery is a function of the battery energy capacity (kWh), the battery initial state of charge (SOC) and the rate (power in watts) at which the battery can be recharged. The battery recharge rate is carefully controlled by the battery management system but has a maximum value limited by either the battery charger power rating or the power delivery capacity of the electric circuit connecting to the EV. Obviously when using the utility ac grid, charging at the maximum rate of the on board charger will minimize the time to recharge an EV regardless of the initial SOC when charging begins.

5.2.1 Battery Energy Capacity

EV battery technology development is a complex chemical and material science engineering task and, while significant progress has been made to increase battery energy storage capacity and operating lifetimes, limitations of EV onboard energy storage remain when compared to ICE vehicles. Battery energy storage is a function of the volume (surface area) of the battery and the materials used. The rate of battery charging and operational lifetime is also affected by the battery chemistry, age, average operating temperature and historical charging and discharge cycles [7].

The relatively short driving range for most BEVs before recharging is needed, coupled with a small number of recharging facilities has given rise to the term “range anxiety” in discussions of EV adoption. The fundamental cause of the difference in driving ranges between most EVs and ICE LDVs is the low energy density of batteries compared to much more concentrated energy that can be contained in an ICE vehicle fuel tank. For ICE vehicles, the fuel tank is only an energy storage container whereas technically for an EV, the combination of the battery plus its charger and control system comprise the energy storage system.

Gasoline has an approximate energy density of 36 MJ/l. A 60 liter fuel tank can be filled in two or three minutes with (36 MJ/l x 60 l =) 2160 MJ or 600 kWh of energy at a filling station. By comparison, a lithium ion battery, with its energy density range of 0.72 to 0.875 MJ/kg, would need to weigh (2160 MJ / 0.8 MJ/KG) 2700 KG in order to store the same amount of energy. The maximum BEV battery capacity shown for a production LDV EV is for a Tesla Model S at 85 KWH or approximately 306 MJ. The fact that the driving range of the Tesla model S is listed in

Figure 2 as 400 km is due to both the higher energy conversion efficiency of the electric drive system as compared to that of the ICE vehicle and also because the Tesla battery is approximately 3.5 times the size of the battery found in other EVs such as the Leaf.

As a very rough approximation, if an ICE vehicle with a 60 liter tank can travel 600 km before refueling, its energy use rating can be approximated as 1.0 kwhr per km. In comparison, the Tesla's high performance electric drive train uses 85kwhr/400 km or a value of just over 0.21 kwhr per km.

5.2.2 Battery State of Charge

The state of charge (SOC) of a battery ranges from 0% (fully discharged) to 100% (fully charged). SOC calculations are complex for lithium ion batteries [8] and a combination of measurement and model based calculations are often employed by a BMS in order to accurately estimate the state of charge. During normal operation the BMS actively tests and recalculates the SOC to confirm that sufficient energy remains in the battery for operation and to update the operator on the need to recharge. The BMS must keep accurate measurement of the SOC during operation in order to avoid battery over-discharging or over-charging. Excursions beyond normal operating limits can result in a loss of life of the battery and also loss of efficiency in the battery charge and discharge process.

5.2.3 Battery Charger Ratings and Required Supply Circuit Configurations

The BMS in an EV is responsible for all aspects of energy input and output from the battery. In Figure 3 AC power is differentiated from DC power by red and green colours respectively while blue interconnections indicate the control the BMS exerts in operation and when charging to balance the twin goals of optimizing battery operating life and providing acceptable recharging times.

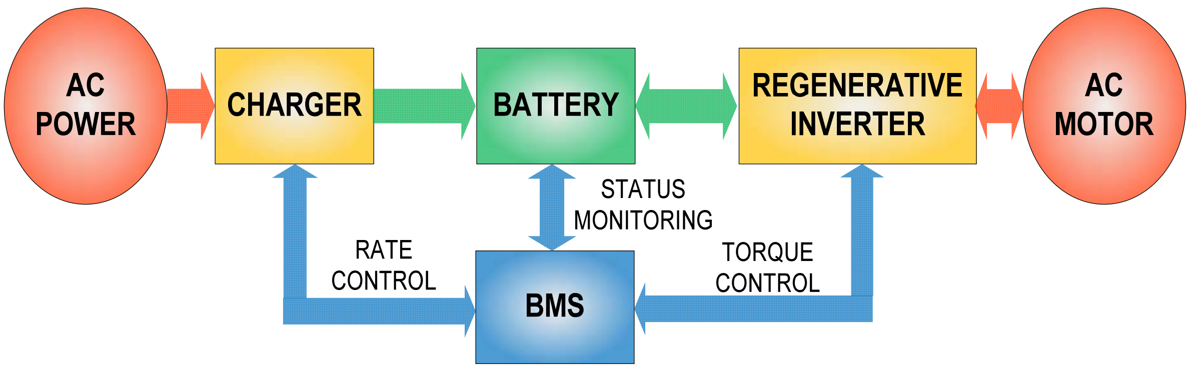


Figure 3 - Generic EV Battery Management System (BMS)

Figure 2 indicated maximum KW ratings of vehicle on board battery charger for various EV models. In many locations the available electrical connection to an EV is rated less than the on board charger capacity. To illustrate this mismatch, Figure 4 summarizes various ac supply voltages and current rating configurations that are commonly encountered for EV charging. It highlights the minimum circuit configuration (volts x amps = watts) in green needed in order to meet the maximum power ratings of the Figure 2 EV on board chargers.

AC Circuit Configuration				EV Type with On Board Charger Rating					
				PHEVs		BEVs			
Volts	Phase	CB (A)	Power (KW)	Chevy Volt	Toyota Prius	Ford Focus	Nissan Leaf	I-Miev	Tesla S Std
120	1	15	1.4						
		20	1.9						
208	2	15	2.5						
		20	3.3	3.3 KW Rated	2.9 KW Rated				
		30	5.0					3.6 KW Rated	
		40	6.7			6.6 KW Rated	6.6 KW Rated		
		50	8.3						
		60	10.0						10 KW Rated
240	2	15	2.9		2.9 KW Rated				
		20	3.8	3.3 KW Rated				3.6 KW Rated	
		30	5.8						
		40	7.7			6.6 KW Rated	6.6 KW Rated		
		50	9.6						10 KW Rated
		60	11.5						

Figure 4 - Common AC Circuit Configurations vs. EV Charger Ratings

Clearly any lower power circuits (yellow) than the on board charger rating (green) can be used but the EV battery will take longer to charge. Conversely, there is no point installing a circuit for EV charging with more capacity than the charger supplied with any EV can utilize (grey).

The variety of vehicle charger power ratings and the multiple and overlapping circuit configurations able to deliver various amounts of power can be one of the early points of confusion for EV adopters.

5.3 EV Charging Methods

Contact based (cord and receptacle) AC circuits form the majority of energy transfer schemes used for EV charging. Circuits to serve plug-in EVs range from relatively low power at 120 volts, to the highest, a 10 KW 240 volt system used for the Tesla S. (Note that, as an option, Tesla S owners can even order their vehicles with dual 10 KW chargers).

Direct current (DC) systems are also supported by many EV manufacturers which allow for higher power ratings because they by-pass the vehicle on-board charger and connect directly to the battery. Higher DC voltages and currents allow charger power ratings of up to 80 KW. The trade off to have access to this very fast battery charging capability is the price of the expensive off board charger and the availability and cost of the large upstream electrical infrastructure necessary. A DC charging system will be illustrated in the next section but not discussed in depth other than to state here that the cost and infrastructure needs for higher power DC chargers make them impractical for most residential applications.

Wireless (non-contact) systems for EV battery charging are available for several types of EVs either as a factory installed option or as an aftermarket modification.

5.3.1 Contact Based Charging

As stakeholders in a new industry look to increase growth, a common practice is to cooperate in the development of unifying standards to the benefit of the industry. This is the case for EV charging where this generation of EV technical standards that address common issues such as power handling, communications, safety and physical compatibility have been evolving since the 1990s.

Global EV charging standards are concentrated in four main regions: North America, China, Japan and the European Union. Although each of the charging strategies reflected in these regional standards are slightly different (to the degree that charging equipment is not interchangeable), the common thread among all standards is that they exist to address similar technical requirements and all are designed to support growth of their target markets. Naturally, if a country includes EV exports as part of their target market, then they are motivated to engage in international harmonization efforts to a greater degree than a country with a strictly domestic market.

In North America the SAE (Society of Automotive Engineers) Electric Vehicle Coupler Standard (J1772) originally set the parameters that had to be met between a conductively connected fixed charging station and an EV in California. The SAE J1772 standard specifies power, safety and communication links from a power source to an EV. Due to the importance of California in the U.S. and global vehicle market, J1772 has become the *de facto* North America standard and has been refined and updated since its introduction in 1996. The 2009 variant of the standard was endorsed by GM, Chrysler, Ford, Toyota, Honda, Nissan, and Tesla. The J1772 coupler standard is a live document and was revised once in 2010 [8] and twice in 2012.

Most EV owners may have a variety of adapter cords and can use a variety of charging stations when recharging their EVs in North America. In doing so, they interact with the J1772 standard regularly and are aware of the basic functionality built into the standard: 1) electricity is transferred only when the EV is correctly connected 2) a safety interlock prevents driving an EV when connected to a charging station cord and 3) varying levels of energy delivery to the connected EV (the maximum charging rate) are available depending on which charging station the EV is connected to.

A more in depth look at EV charging principles, particularly the communications between the EV and the land based power source, is outlined in following sections. The communications functionality inherent in J1772 is critical for the mitigation of the future building electrical system impacts which would accompany large scale EV adoption.

5.3.1.1 J1772 Charging Levels

Charging levels as defined in the J1772 standard are as per Figure 5. As the complexity and power handling of the AC and DC levels increase, so too does installation and maintenance costs (equipment, wiring), the chargers impact on building electrical systems (KW demand and potential power quality issues) and local electrical utility upstream loading concerns.

Charge Method	Supply Voltage to ESVE (V)	Supply Phase	Supply Voltage to EV	Max continuous current (A)	Max. Power (KW)
AC Level 1	120 AC	1	120 VAC	12/16	1.4 / 1.9
AC Level 2	208 to 240 AC	1	208 to 240 VAC	80	16.6 / 19.2
DC Level 1	As Needed	1 or 3	200 to 500 VDC	80	16 / 40
DC Level 2	As Needed	3	200 to 500 VDC	200	41 / 100

Figure 5 - Summary of J1772 Charging Levels

The EV community generally follows the AC level 1 and 2 conventions in normal discussions. DC chargers are often referred to as Level 3 meaning high power DC fast charging.

5.3.1.2 J1772 Level 1 and 2 AC Charging

A 5 pin connector assembly in a plug configured as shown in Figure 6 meets the J1772 level 1 and 2 AC requirements.

Function - Connector	Contact	Function - Vehicle	Description
AC power L1	1	Power	Power connection
AC power L2 or N	2	Power	Power or neutral connection (208/240 or 120 volt respectively)
Equipment Ground	3	Vehicle Chassis Ground	Connect ESVE equipment ground to EV chassis ground - safety
Bidirectional Control Pilot Signal	4	Bidirectional Control Pilot Signal	Variable signal for bidirectional communications between ESVE and EV
Proximity Detection	5	Proximity Detection	Allows EV to detect/confirm charging connector - charging and vehicle motion safety

Figure 6 - SAE J1772 AC Level 1 and 2 Contact Functionality

Contacts 1, 2 and 3 are power and safety ground related. Contact 5 is monitored in the EV to apply an interlock in the vehicle drive system but also it is used to detect when the plug is being removed. The connector system is designed so that there is sufficient time between the detection of the separation of contact 5 and the power contacts coming apart for the vehicle battery charger to ramp down its output (and hence its input) so as to prevent arcing and damage on the separating electrical contacts.

Contact 4 is a variable signal (modulated square wave plus two distinct voltage levels + or – 12 VDC) that is used by the ESVE to communicate with the EV. The EV can affect the signal level on contact 4 by changing the impedance seen by the ESVE communications controller. The full extent of this signaling capability is the subject of ongoing standards development. The functionality of contact 4 in EV communications includes:

1. The ESVE signals the EV the maximum current (power) draw that it can deliver before charging starts. The intent is to make the EV charger draw only the power that the circuit it is connected to can safely provide. A maximum current value is physically built into some low power ESVE to satisfy the communications protocol while limiting the current draw to protect premises wiring. In some higher price ESVE, the maximum current value can be configured by the EV user.

2. At any point during a charge cycle, the ESVE can signal to the EV BMS a change in the maximum current available that can be supplied. Upon receiving this signal, the EV BMS must adjust its power input within 5 seconds to match the command. In other words, the standard includes provisions that the car charger power draw can be externally controlled at any time during the charging cycle.

Irrespective of what the load is an electrical circuit is supplying, any attempt to draw more power than can safely be delivered in a properly designed electrical circuit will always be prevented by protection devices such as fuses or circuit breakers. In the case of EV charging, the initial handshaking between ESVE and EV is to permit the vehicle to recharge in the shortest possible time while preventing unexpected circuit openings due to overloading detected by the protective devices.

5.3.1.3 J1772 Level 1 and 2 DC Charging

DC charging is similar in approach to that for AC but with higher power ratings. The higher power ratings are because DC charging by-passes the constraint of the vehicle on board charger and delivers energy directly to the vehicle battery. For most commercially available EVs the ESVE for DC charging are very expensive as they duplicate the power electronics needed to convert AC to DC on the fixed equipment but at a higher rating than exists on the vehicle. Similarly, the AC circuits that provide the power to the DC ESVE for conversion must be sized for the power duty.

The J1772 version of DC charging provides for DC and AC charging stations via a combination 7 contact connector as per Figure 7. Contacts 1 and 2 function as AC or DC level 1 connection points and the ESVE determines which circuitry to connect internally to transfer energy to the EV. Other functionality is similar to AC charging. Note that the ability of an EV to connect to a DC charger is specific to the vehicle.

Function - Connector	Contact	Function - Vehicle	Description
AC Line 1 or DC Level 1 +	1	Power	Power connection
AC Line 2 (or N) or DC Level 1 -	2	Power	Power or neutral connection (208/240 or 120 volt respectively)
Equipment Ground	3	Vehicle Chassis Ground	Connect ESVE equipment ground to EV chassis ground - safety
Bidirectional Control Pilot Signal	4	Bidirectional Control Pilot Signal	Variable signal for bidirectional communications between ESVE and EV
Proximity Detection	5	Proximity Detection	Allows EV to detect/confirm charging connector - charging and vehicle motion safety
DC Level 2 - Positive	6	Power	Power connection
DC Level 2 - Negative	7	Power	Power connection

Figure 7 – DC and AC Combination Contact Functionality

5.3.2 Wireless Charging

While the direct connection method will always be the most efficient method to transmit electrical energy, progress on wireless energy transfer to an EV has continued to develop from earlier inductive types used in the 1990 EV era.

Development in several technologies for wireless power transfer (WTP) has been motivated by the projected market for EV battery charging [10]. Plugless Power is a commercially available product using resonant inductive power transfer (RIPT) and is available factory installed or as aftermarket additions for the Chevy Volt and Nissan Leaf in North America.

The RIPT principle of operation is the same as wireless inductive charging of many household items presently in use such as wireless headphones and toothbrushes but with larger power ratings. The transfer of energy relies on a tuned resonant circuit where the power electronics and a fixed winding form the stationary portion of the ESVE and the secondary winding and battery output electronics are on board the EV.

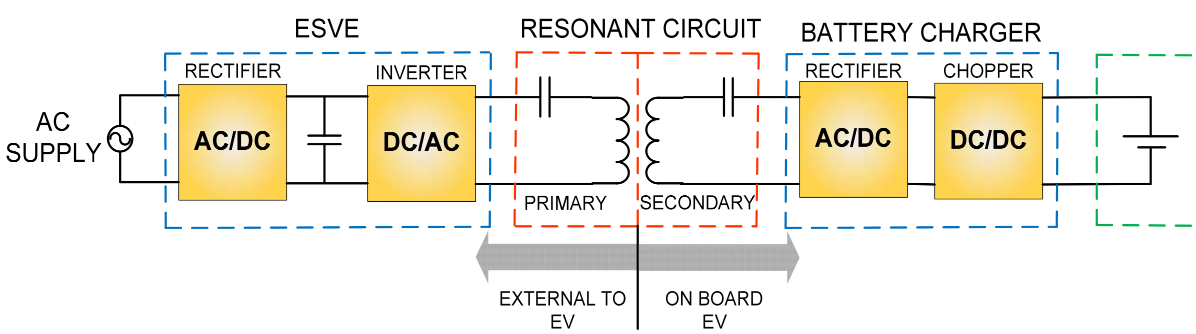


Figure 8 – Generic EV Wireless Charging Diagram

As shown above, the incoming AC supply is first rectified to DC and then inverted to form a relatively high frequency AC voltage. When the appropriately tuned secondary winding is physically in place to maximize coupling through an air gap above the primary winding, energy is transmitted to the EV and then rectified and voltage adjusted to charge the battery.

Estimates of the power lost in the air gap vary depending on technology with proponents claiming from 2 to 3 % increased losses in a wireless system as compared to a contact based system. These estimates may under represent the actual losses as they are claimed under ideal conditions.

Amongst the challenges for this technology are the efficiency losses mentioned and also the practical considerations such as how to install the fixed primary winding below an EV in a parking stall in a way it will not be damaged.

One of the less apparent but potentially major issues, as yet not resolved, is assessment and quantification of any health risks associated with the high frequency magnetic and accompanying electric field inherent in this technology.

Another WPT system that uses low instead of high frequency magnetic and electric fields has been developed at UBC [11] and has been under test for several years. This system uses permanent magnets and the principle of rotating synchronous machine energy transfer to magnetically couple a revolving rotor on a land based transmitter to a revolving rotor on a vehicle based receiver. The synchronous rotor in the vehicle turns an onboard generator to provide battery charging.

Overall, the convenience of WPT technology is very attractive and can be seen as another factor which will contribute to EV adoption. SAE is in active development of an EV wireless charging standard (J2954) to deal with the similar issues for wireless charging as J1772 does for contact based systems. The J2954 standard will naturally exchange details of physical cord connectors for considerations such as alignment tolerances of primary to secondary windings but the main content such as: safety, operability, standardization of power levels, wireless vehicle to grid communications and smart grid programmability will be maintained and built upon.

6 EV Regulations

EV regulations are similar to the technical standards outlined in the previous section in that they are developed as a response to an emerging technology or, a technology expected to emerge. The difference in development of standards as compared to development of regulations is that standards deal with issues technology stakeholders agree are necessary to grow the market whereas regulations seek to control the manner of adoption of the new technology. Significantly, regulation creates opportunities for authorities to actively influence consumer sector technology adoption to the point where technologies can be promoted or discouraged.

6.1 City of Vancouver – Electric Vehicle Provision Regulations

Urban centers within B.C. rely on the B.C. Building Code with local amendments to govern design and construction practices. In 2009 the City of Vancouver (COV), at the urging of internal and external EV advocacy groups, included requirements in their bylaws [10] mandating provision for EV charging in new construction. These regulations came into effect in 2011 and directed that all new multi-resident buildings (minimum of three dwelling units) must include a receptacle for EV charging for 20% of their parking stalls. Additionally, the regulations require that the building electrical room include sufficient space to install any equipment needed to provide charging for 100% of residents in future. It is unclear that there was any intent on the COV's part to dictate the individual EV charger levels but only that "provision" is to be made in new MURB construction. This approach is similar in kind to that implemented in California in 2011 [11] which mandated provisions for single family dwellings and also gave a target of 10%

of MURB unit parking spaces to be equipped with EV charging infrastructure. The California report also decided that Level 2 charging was appropriate for consumer overnight plug in needs to accommodate foreseeable trends.

To assist the public in responding to this regulation, the COV referred stakeholders to a 2009 BC Hydro produced document [12] for EV infrastructure within B.C. This document includes a flow chart (Figure 4-9 on page 33) which gave an indication of the steps needed for installation of EV charging in a retrofit MURB scenario. The flow chart is complex and illustrates that retrofitting MURBs for EV's is involved and can be costly. This 2009 study was updated in 2013 [13] and, while the complex flowchart remains unchanged (now Figure 4-13 on P 4-15), additional materials have been added to the MURB residential charging section 4-5. These new points show increased recognition of MURB governance issues, potential electrical upgrade needs and discussion of electrical demand management in MURB EV retrofit scenarios.

6.2 Canadian Standards Association – Electrical Code

Electrically, EV charging installations are governed by the relatively new Section 86 of the Canadian Electrical Code [14]. The EV related code requirement that creates the most impact on building electrical system design is not in section 86 but is rule 8-202(3)(a)(d). This rule in the Circuit Loading and Demand Factor section of the code states that any EV charging equipment not located (fed from) a dwelling unit in apartments or similar buildings must be included at a 100% demand factor (i.e. no de-rating for diversity with multiple users) in calculating the service entrance feeder size. For cost and safety reasons, it is extremely unlikely that any EV charging circuit will be routed back to an individual suite's electrical panel as parking area loads are almost always fed from the relatively close, accessible and separately metered "house" distribution found in MURBs. Rule 8-202(3)(a)(d), whether for new or existing MURBs, may not necessarily affect the incoming service size for new buildings but will certainly increase the capacity and amount of installed equipment at points between the service entrance and the EV charging circuits for any significant EV deployment.

In existing buildings, the costs associated with upgrading electrical infrastructure can negatively influence strata owners individually or via the strata council as to the number and type of EV charging outlets to install. For instance, level 2 chargers can require up to 4 times the power capacity of level 1 chargers (8 KW versus 1.9 [1] KW) and all electrical equipment ahead of the EV chargers within the building must have the capacity carry the sum of the aggregate charger load (number of level 1 or 2 chargers multiplied by the power ratings of those chargers).

7 EV Stakeholders

7.1 Utility

The three blocks representing the utility shown in Figure 1 provide a convenient method to illustrate that the utility must have the generation, transmission and distribution capacity to meet the time varying nature of their normal loads plus the effect of any new load in real time. This fact is somewhat unique in electric utility operations when compared to other types of energy generation, transportation and distribution systems because of the physics of electricity. There is no inherent electricity storage capability in the system and electrical power must have

[1] CEC Rule 86-306 states that 120 volt EV circuits shall be rated at not less than 20A.

a use in order to be created. When the connected load changes the utility system components react as a system to match the change in a manner which is invisible to energy consumers.

Daily patterns of electricity use in individual residences follows a standard shape (load profile) on weekdays and a slightly different one on weekends.

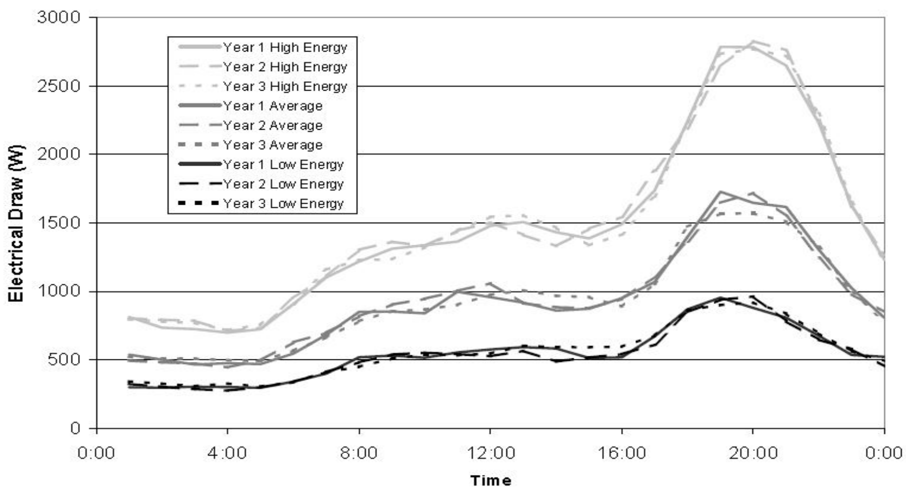


Figure 9 – Generic Daily Residential Electric Load Profiles – No EV charging [17]

A generic representation of Canadian residential weekday electricity use for high, medium and low scenarios over a three year period is as shown in Figure 9 and, although variation in the shape of load profiles occur season to season and by country, the general shape is consistent [17] [18].

Residential electrical demand is lowest between midnight and about 6 AM and a daily demand peak occurs in the early evening. A modification to the generic profile described by B.C. Hydro [19] is that in B.C. there is a small morning demand peak from 6 to 9 AM in addition to the larger evening peak that occurs between 4 to 9 PM.

As Figure 9 represents only one residence, it follows that the aggregate behaviour of number of residences supplied from a common source will result in that source experiencing the common load profile. In electrical terms, the overall utility system and all its many individual components must have the capacity to supply (meet) the peak electrical demand they experience without damage or degradation in performance. Presently, B.C. Hydro as a system, has sufficient generation, transmission and distribution infrastructure to meet the sum of residential, commercial and industrial peak demand experienced under normal operating conditions. However, if there was a relatively sudden appearance of new loads due to a sharp increase in EV adoption rates in localized geographic areas, that could certainly overload neighborhood distribution system transformers and wiring [19] infrastructure despite the rest of the utility system remaining within operating parameters.

Unlike B.C. Hydro, many utility systems either cannot call on large amounts of rapidly available generation or have other infrastructure or operational constraints in their systems that make them unable to meet the naturally occurring daily or seasonal demand peaks they experience. Utilities in this situation must keep the maximum load demand matched to their delivery capabilities in order to maintain the parameters critical to users and not overload their equipment past practical limits. Among the methods used to achieve this are differing forms of demand control. These range from turning off an area or subset of customers to instructing customers to reduce demand to using incentive methods to shift customer demand to non-peak times during the day when the utility system is able to meet the demand.

Much of the literature [21] [22] [23] studying the potentially large effect of future EV charging on utility electrical systems relates to supply constrained utility systems. In these studies, EV charging is often examined analytically in terms of queuing theory and least cost consumption analysis. However, as EV adoption has gained a foot hold in certain U.S. cities recently, actual data is becoming available on the effectiveness of utilities using varying electricity prices (Time of Day – TOD pricing) to shift the impact of the EV charging demand from the peak evening hours to the hours after midnight in order to smooth the demand load on their systems. Data for San Francisco [15] (Figure 11-2 on P 11-6) shows that TOD pricing can provide dramatic results in shifting EV loading.

Although B.C. Hydro has taken significant steps to implement the province-wide smart meter infrastructure which supports TOD metering (in addition to providing other useful functions), B.C. Hydro`s public position is presently that TOD metering rates will not be employed in B.C. This position will most probably change in future.

7.2 MURB Developers and Builders

From a developers first recognition of a MURB opportunity, through the land acquisition process, to architect and marketing concepts, negotiations with municipalities and financiers, preliminary design and cost development, detailed design and construction tenders until the time that the MURB units are completed and available to the public, the business mandate is to maximize the profit within a competitive market while providing a facility which meets all design goals and regulatory requirements.

Developers will not include features or capabilities in any design for which there is no end user demand or for which there is no return. They will however, embrace features which will give their project a competitive advantage in the marketplace. Making provision for EV charging in new urban MURBs falls increasingly within developer considerations for some locations.

7.3 End Consumers/Strata Councils

EV buyers today are early technology adopters. To date in many locations, their motivations to choose an EV are often not shared by the majority of their MURB neighbors. The nature of a MURB is that while the residential areas are private, the balance of the building including parking areas are usually a common area for which the costs and benefits are shared according to the strata rules.

Generally in B.C., MURBs can associate with one of two organizations. If the building is rental, then building owners and property managers can belong to the B.C. Apartment Owners and Managers Association. If the MURB is a strata or self-owned type, an organization called the Condominium Home Owners Association (CHOA) welcomes membership from strata corporations, individual owners, businesses that serve the strata industry and governmental agencies. CHOA seeks to provide advisory services, education, advocacy and other types of services for its members.

In a MURB landlord/tenant arrangement the landlord will respond to tenant requests for EV charging and make a single decision. This is a much more straightforward process than in a strata building.

In adding personal experience with one Vancouver MURB investigated to other interview results [24], the following is a partial list of complicating factors which can slow the speed and efficacy of EV infrastructure installations in strata MURBs:

- Lack of clarity as to who owns (or leases) the parking stalls.
- Who will purchase and own the ESVE? What will occur if a suite owner pays the installation costs and then moves?
- Who will pay for the installation?
- What are the liability issues – personal or 3rd party damages – associated with an EV installation?
- Who will pay for the energy costs and how will costs be apportioned (in a multi EV installation)? What are the legal parameters regarding reselling electricity? Who will administer energy usage and what technical skills are needed to track and invoice?
- Which stalls will receive EVSE? Interested owner(s), guest parking? Will the access be dedicated to one user or will the outlet be shared? If shared, how will access be controlled?
- What number and capacity of outlets is needed? What will be the mix of level 1 and 2 circuits? What brand of ESVE will be chosen and with what features?
- What is the capacity of the building electrical system to add EV charging? What is involved?
- If provisions are made for one or two EV owners now, what will happen in future if more want EV charging access? What is the precedent being set and limits needed?
- Need for a quorum (usually 75% of the owners) to vote on expenses and difficulty obtaining this from non-engaged owners.

At this time, CHOA has commissioned a report [24] focussing on governance and legal issues, some of which are mentioned above, which will likely be made available to their membership in the near future to provide guidance on many points.

8 EV Charging – Present Day Impacts on MURB Electrical Systems

8.1 New Versus Retrofit MURBs – General Comments

The unit costs of any single task will always be lower in new construction than for retrofit construction as long as the work involved was included in the new construction tender price. This is due to two reasons: first and obviously, the new construction pricing was obtained under competitive market bidding conditions. Second and less obviously, real costs for materials and for unit labour are higher in a retrofit situation than they are in new construction.

In new building construction, contractors are purchasing large volumes of the necessary materials – in the case of electrical contractors these materials range from distribution equipment, to panel boards to conduit to wire – at the best volume prices available. Usually, after an electrical contractor is successful in obtaining a project, a second round of bidding or sustained negotiations are held between the electrical contractor and material suppliers to drive down material costs. Also, opportunities occasionally exist whereby a knowledgeable contractor can work with the design team and owner to adjust some aspects of the tender design in order to reduce costs while meeting code rules and the overall design intent.

During construction, the project electrical foreman organizes available personnel, equipment and methods to the contractor's best advantage. This can entail, to name only a few examples: using other trades equipment and/or sharing costs for items such as scaffolding; breaking installation tasks into simpler pieces suitable for less expensive apprentice labour; always choosing the shortest practical routes for wiring by locating conduits in poured floor slabs of parking levels; using knowledge of the construction schedule to staff the project only with the minimum number of workers needed so that the workforce is always at its most productive.

By comparison, installation in retrofit situations means buying materials on a small volume, more expensive piece meal basis, using an experienced electrician who can handle any tasks as they arise and taking whichever routes are available to get a circuit from point A to B. Often, for EV installations in MURBs, this can mean a longer wiring route that includes coring (drilling) holes in concrete walls and floors and working around owner vehicles and traffic according to non-optimum construction schedules.

These higher material and labour costs for retrofit installations are accompanied with by higher overhead costs including those for a service truck if used, larger pro-rata costs for office staff overhead and a higher percentage profit necessary for each project.

Description	New Construction	Retrofit Construction	% Change
120v 20A EV Circuit 25m linear distance, panel existing, 20A outlet only	$465	$1,137	245%
208v 40A EV Circuit 25m linear distance, panel existing, no ESVE	$642	$1,451	226%

Figure 10 - Comparison - EV Circuit Costs - New versus Retrofit Construction

Figure 10 is a summary of high level cost estimates to highlight the range of differences between new and retrofit construction. Details of this estimate are located in Appendix C.

For discussion purposes, it is helpful to segment the installation, cost and other impacts of EV provision in MURBS into two sections:

1) The number and type of EV circuits to be supplied from local panel board(s) out to all charging stations/ESVEs and
2) The aggregate impact of EV electrical load on the building electrical equipment from the EV supply panel board(s) back to the building incoming point of electrical supply.

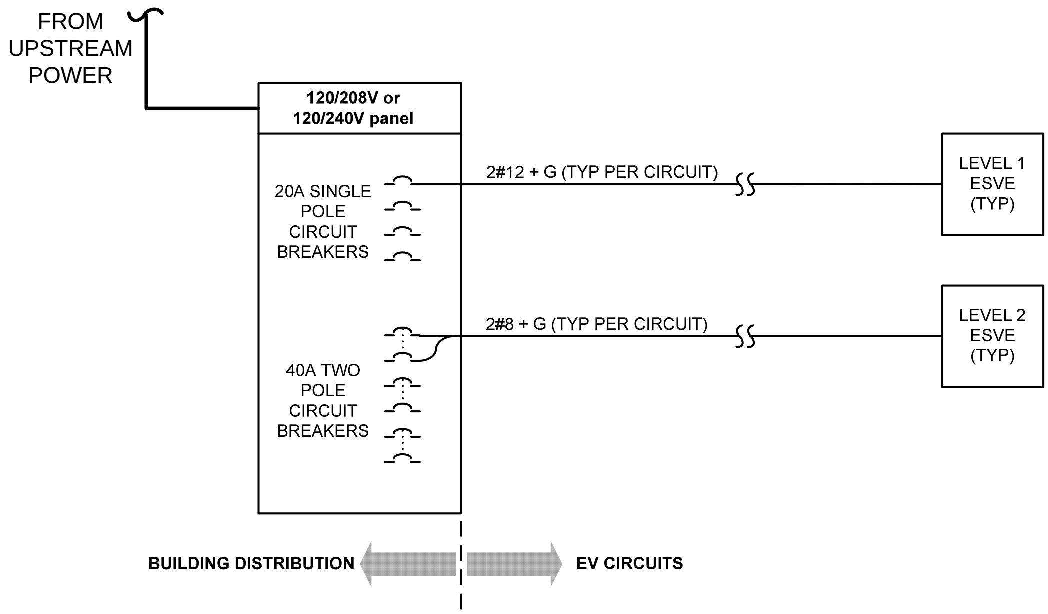


Figure 11 – Panel Board to EV Circuit Demarcation Diagram

From figure 11, the number, size, location and final ESVE type for circuits are the parts of EV installations that are visible outside of electrical room(s) and most easily understood in terms of costs. The electrical details of EV charging circuits external to a local panel will not be discussed past this point in depth. Rather, it is the less visible impact of EV charging additions to the upstream building electrical distribution system that will be reviewed from this point forward.

8.2 New MURB Facilities

The planning for EV installations in new MURB construction is straightforward in terms of basic electrical design. The standardized steps are:

1) Regulations specify the amount of EV parking stall coverage and the developer and/or electrical engineering consultant decides the power rating mix of level 1 or 2 circuits.

2) CEC section 8 governs how the additional KW demand loads for EV charging are calculated for building electrical distribution system design and CEC section 86 governs wiring methods.
3) Building layout and design team planning processes decide where in the building parking the EV charging stalls will be located.

With the above three points finalized, standard electrical design practice is used to determine how best to integrate the EV circuit loads into the building distribution design and how to locate and size the EV supply panel(s) and run the mix of circuits needed. Typically, EV charging parking stalls in mid to large size MURBs will be fed from the "house" or common area distribution located relatively near to the parking levels. In these types of buildings, electrical distribution will usually be three phase and so the level 2 outlets will be 208 volt and not 240 volt circuits.

Building Parking Stalls	Required EV Stalls	Mix % at 120 V @ 20A (balance 208 V @ 40A)				
		0	25	50	75	100
		KW Demand per CEC				
10	2	13.2		8.5		3.8
20	4	26	22	17	12	8
40	8	53	43	34	25	15
60	12	79	65	51	37	23
80	16	106	87	68	49	30
100	20	132	109	85	62	38
120	24	158	130	102	74	46
140	28	185	152	119	86	53
160	32	211	174	136	98	61

Legend at 120/208 V 3 Phase
- 100 A Panel
- 225 A Panel
- 400 A Panel
- Multiple Panels

Figure 12 - KW Loading vs. EV Circuit Mix for EV Charging Parking Stalls @ 120/208V

Figure 12 illustrates the aggregate power requirements that need to be designed into the building system as a function of the mix chosen of 120 volt level 1 and 208 volt level 2 charging circuits assuming the COV 20% provision mandate. The 120 volt circuit is the 20A version of

J1772 AC Level 1 charging with a power rating of 1.9 KW. The 208 volt circuit is the 40A version of J1772 AC Level 2 charging with a 6.6 KW capacity. Note that the Level 2 circuit rating in this example matches the maximum on board charger requirements for all vehicles listed in Figure 2 except for that needed for the larger 10 KW Tesla Model S.

Panel boards containing multiple branch circuit breakers are standardized on current carrying ratings (ampacity) as shown in legend of Figure 12. Each current rating size is available in several physical sizes, each of which takes a different number of circuit breakers. Figure 12 shows approximate break points where the panel boards must change sizes based on current ratings given the mix of circuits contained. The simple ratio of circuit power requirements (6.6/1.9 = 3.5 in the case of this example) represents the number of Level 1 charging circuits available for a single level 2 charging circuit.

If the parking areas are large, as in a mixed use commercial/MURB tower complex, it is likely some or all of the common area power distribution system will be at a higher voltage level i.e.: 600 volts in Canada. This permits the use of 600 volt feeders to dedicated EV transformers and panel boards per Figure 13. In turn, this distributes EV charging power efficiently and also limits the maximum EV demand to the combined total of the EV parking transformer ratings

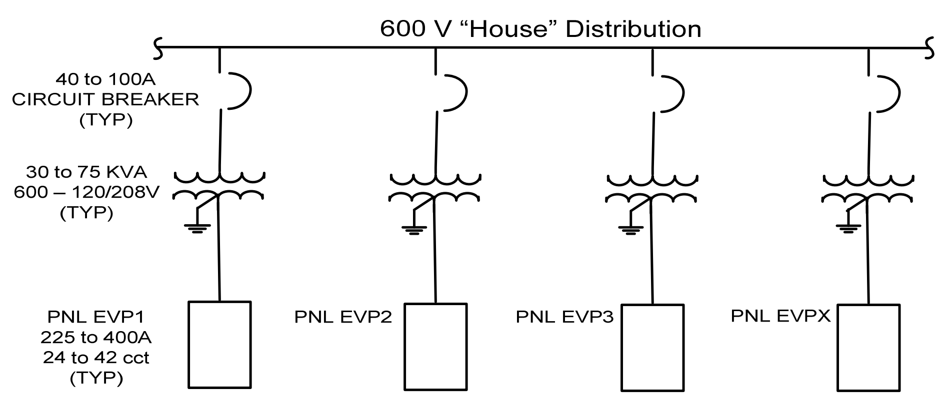


Figure 13 - Use of Distributed EV Charging Panel boards from 600 Volt House Distribution

Questions faced by end consumers and strata councils as to who is to be allocated spaces, how energy costs are to be recovered and similar such problems are largely deferred in new MURBs until the building is occupied.

It should come as no surprise that the letter of the regulatory intent regarding COV EV charging provisions is followed in building design but no more. Building designs inspected in Vancouver show that the local panel boards in parking areas are provided sized to hold a mix of level 1 and 2 charging circuits. Some new MURB designs include a 60/40 split for level 1/level 2 charging circuits and some are primarily level 1. The wiring exists from these parking level panel board(s) out to the designated EV parking stalls where a simple receptacle is installed. The circuits are often combined and routed to minimize the installation costs according the electrical code rules.

The pending issue of measuring individual circuit EV energy consumption for future user cost recovery schemes can be met in new building electrical designs by reserving wall space immediately adjacent to the designated EV panel board for a current transformer and transducer cabinet [25]. This cabinet includes a small current sensor for each circuit through which one wire of the EV circuit passes. This signal given by the transducer is proportional to the current in the wire. Knowing the circuit voltage, the current versus time information is accumulated and sent to a central data collection agency which, under agreement with the building management company or strata council , can generate invoices for energy used per circuit on whatever reporting time basis is needed i.e.: monthly.

Anecdotally, some systems have been installed using this type of equipment locally but the participation threshold for users to justify the monthly administrative costs is often more than 5 to 10 users and is interlocked with the position a strata takes on recovering costs.

The relative discrepancy between the expense of individual metering systems and the low cost in B.C. of electricity is often another factor which prevents movement on relatively expensive metering schemes such as previously described in a residential building. As an illustration, assume a metering system costs $6000 at the time of construction for equipment and installation and $200 per month to administrate. Assume there are 10 EV users in a building each driving 15,000 km a year with vehicles who use 0.2 kwhr per km. That is a total of 10 x 15,000 x 0.2 = 30,000 kwhrs per year for EV use. Then, assume the cost of electrical energy is $0.10 cents per kwhr. The total energy cost is $3000 per year or $3000/ (10 x 12) = $25 per month per EV user. Again, using very rough estimates, the system used to measure and attribute energy cost to users has at best a 2 year payback <u>if</u> the EV users were not only charged for their energy consumption (by law they cannot be charged for more than the sale price) but also each user had to pay $20 per month pro rata administrative cost on top of their $25 per month energy cost. Regardless of the accuracy of the cost estimate for the metering system shown here, it is clear that the low cost of electricity in B.C. does not contribute to making a traditional business case for individual residential metering systems without a relatively high volume of EV users in a MURB.

Appendix A contains an example of a market housing condominium tower located at UBC and describes how the developer has voluntarily made provision for EV charging despite UBC not being governed by the COV regulations.

8.3 Existing MURB Facilities

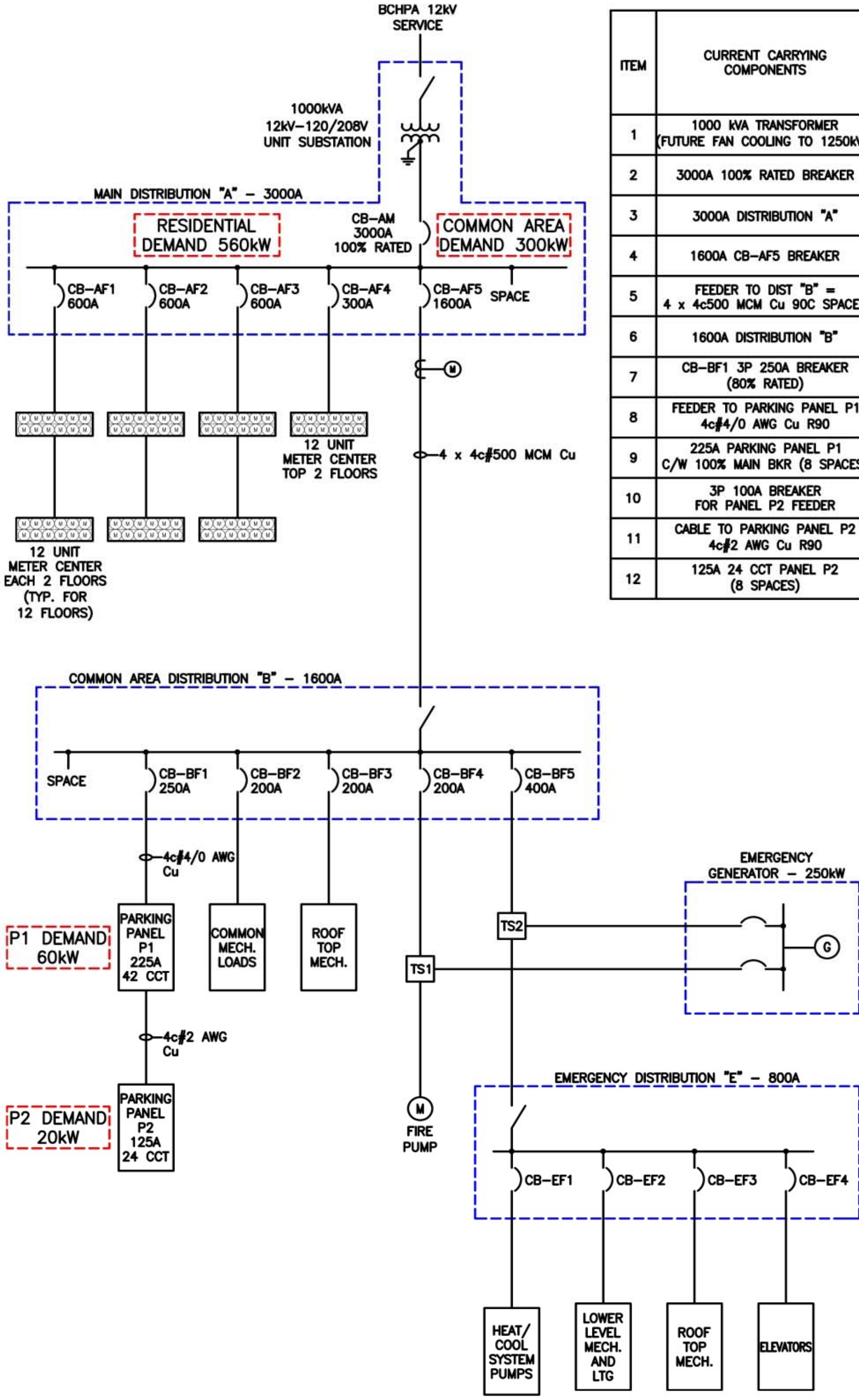
The impact of EV charging on existing MURB building electrical systems is a function of three factors:

1. The amount and type of EV charging to be added – the net KW value
2. The configuration and capacities of the building electrical system
3. The degree to which the building electrical system is loaded before any new EV loads must be added. (Note that this "base" demand load will vary seasonally, with building occupancy levels and daily with a shape similar to that shown in Figure 9)

As an illustration of these factors consider a hypothetical situation where a strata council is examining the addition of up to 8 level 2 charging circuits to their 5 year old, 14 floor condo tower in Vancouver. They have no dedicated EV charging to start with and four of their building owners are interested in having EV charging available in the building although only two of these owners have EVs presently.

They are aware via their association that EV charging additions are not to be rushed into if substantial amounts of level 2 charging is being considered but feel that, if they have four owners very interested now, they would look at what effect twice that number of level 2 chargers would have on their building before committing to any action. They have engaged the original building electrical consultant to conduct the investigation and report back.

The single line drawing for this building is shown in figure 14.



ITEM	CURRENT CARRYING COMPONENTS	CASE 1 – DESIGN CASE			
		EQUIP. RATED CURRENT (A)	DESIGN DEMAND (kW)	DESIGN DEMAND CURRENT (A)	CURRENT AS % OF RATED (A)
1	1000 kVA TRANSFORMER (FUTURE FAN COOLING TO 1250kVA)	2776	860	2513	91%
2	3000A 100% RATED BREAKER	3000	860	2513	84%
3	3000A DISTRIBUTION "A"	3000	860	2513	84%
4	1600A CB–AF5 BREAKER	1280	300	877	68%
5	FEEDER TO DIST "B" = 4 x 4c500 MCM Cu 90C SPACED	1720	300	877	51%
6	1600A DISTRIBUTION "B"	1600	300	877	55%
7	CB–BF1 3P 250A BREAKER (80% RATED)	200	50	146	73%
8	FEEDER TO PARKING PANEL P1 4c#4/0 AWG Cu R90	260	50	146	56%
9	225A PARKING PANEL P1 C/W 100% MAIN BKR (8 SPACES)	225	50	146	65%
10	3P 100A BREAKER FOR PANEL P2 FEEDER	80	20	58	73%
11	CABLE TO PARKING PANEL P2 4c#2 AWG Cu R90	130	20	58	45%
12	125A 24 CCT PANEL P2 (8 SPACES)	100	20	58	58%

Figure 14 - Generic Condo Tower - Simplified Single Line Diagram (CASE 1)

The single line drawing indicates voltage levels, types of equipment, current ratings and other high level information relevant when considering electrical systems. Power flow starts at the top of the drawing and proceeds downwards. (Refer to Appendix B for further details on initial building design calculation methods and full step by step diagrams of incremental EV additions used in the example).

In figure 14, the building shows a total calculated electrical demand of 560KW of residential demand plus 300 KW of common area demand or 860 KW in total for the building. The council has asked to see the effect of adding EV charging circuits in steps of 2 level two chargers (2 x 6.6 KW = 13.2 KW) to parking level panel board P1.

Item	Current Carrying Components	CASE 1 DESIGN CASE % Capacity	CASE 2 Add 2 x Level 2 % Capacity	CASE 3 Add 4 x Level 2 % Capacity
1	1000 KVA Transformer (future fan cooling)	91%	92%	93%
2	3000 A 100% rated breaker	84%	85%	86%
3	3000A Distribution "A"	84%	85%	86%
4	1600A CG-F5 breaker (80% rated)	68%	72%	74%
5	Feeder to Dist "B" = 4 x 4c500 MCM Cu 90C spaced	51%	53%	55%
6	1600 A Distribution "B"	55%	57%	60%
7	CB-BF1 3p 250A breaker (80% rated)	73%	93%	111%
8	Feeder to Parking Panel P1 4c#4/0 MCM Cu R90	56%	71%	85%
9	225A Parking Panel P1	65%	82%	99%
10	3p 100A breaker for Panel P2 feeder	73%	73%	73%
11	Cable to Parking Panel P2 4c#2 Cu R90	45%	45%	45%
12	125 A 24 cct Panel P2 (8 spaces)	58%	58%	58%

Figure 15 – Impact on Generic Building Electrical System for EV Load Addition – Cases 1 to 3

Figure 15 shows that the relative effect of increasing EV charging load in 13.3 KW steps at parking panel P1 (Item 9 in the table) varies depending where the electrical system is being examined. The first step in demand load increase (from the Design Case 1 to Case 2) can be accommodated within the building distribution system with no changes other than perhaps adding some circuit breakers to panel P1 for the two 40A EV circuits. Adding the next two level two chargers to move from Case 2 to Case 3 however overloads the circuit breaker (Item 7) that feeds panel P1 and fully uses panel P1's capacity. Therefore, to make the next step in EV circuit addition resulting in a total of 4 level two charger circuits, a number of components (items 7, 8 and 9) would logically need to be upgraded together.

Figure 16 includes the changes to items 7, 8 and 9 which allows the Case 3 loads to be added (now referred to as Case 3a). The estimated cost to increase the size of these three items is approximately $10,000 (breakdown included in Appendix B.)

Item	Current Carrying Components	CASE 3a Add 4 x Level 2 % Capacity	CASE 4 Add 6 x Level 2 % Capacity	CASE 5 Add 8 x Level 2 % Capacity
1	1000 KVA Transformer (future fan cooling)	93%	95%	96%
2	3000 A 100% rated breaker	86%	88%	89%
3	3000A Distribution "A"	86%	88%	89%
4	1600A CG-F5 breaker (80% rated)	74%	78%	81%
5	Feeder to Dist "B" = 4 x 4c500 MCM Cu 90C spaced	55%	58%	60%
6	1600 A Distribution "B"	60%	62%	64%
7	**CB-BF1 3p 400A breaker (80% rated)**	69%	82%	94%
8	**Feeder to Parking Panel P1 4c#500 MCM Cu R90**	52%	61%	70%
9	**400A Parking Panel P1**	56%	66%	75%
10	3p 100A breaker for Panel P2 feeder	73%	73%	73%
11	Cable to Parking Panel P2 4c#2 Cu R90	45%	45%	45%
12	125 A 24 cct Panel P2 (8 spaces)	58%	58%	58%

Figure 16 -– Impact on Generic Building Electrical System for EV Load Addition – Cases 3a to 5

With Case 3a within all component limits, the next step is to move to Case 4 to reach a total of 6 level 2 chargers in the building for which all capacity loading remains within limits. Case 4 to Case 5 allows reaching a total of 8 level two chargers in the building with a net 53 KW of additional demand and all components also remain within equipment ratings.

In summary, to achieve 8 level two chargers in the building the costs include:

1) Cost of building electrical distribution upgrade \$ 10,000[2]
2) Cost of 8 individual level 2 circuits = 8 x \$1200[3] each = \$ 9,600
3) Cost of the individual vehicle level 2 ESVE \$600 to \$2000 each

The strata council recognizes that item 1) above is a building electrical infrastructure issue driven by addition of a certain amount of power. They also understand that the 8 level 2 circuits also equate to (8 x 6.6KW/1.9KW) = 27 level 1 circuits on a power basis but have different costs. The total for item 2) varies according to the scale of the level 2 circuit implementation. Fewer circuits installed will raise the unit costs as will more distinct locations, longer distances etc.

The costs for item 3) vary depending on the sophistication and type of level 2 EVSE chosen.

If the strata council decided that they wanted to have twenty percent of their parking stalls (assuming 20% of 84 units = 16 stalls) EV equipped with level two chargers then the effect would be to add another four cases to this progression. By inspection of figure 16, clearly this would result in at least one more upgrade of items 7, 8 and 9 and possibly forcing item 1, the building main transformer, to apply additional cooling fans in order to keep it with design tolerances.

This example serves to illustrate the pattern that will occur in existing MURB electrical distribution systems with relatively large EV implementation using existing design rules. Small additions should normally have no effect but, as loads increase, differing distribution system

[2] See Appendix B
[3] \$1451 retrofit value shown in Figure 10 reduced to reflect larger economies of scale with 8 versus one or two circuits.

components will need to be upgraded. These step changes in distribution equipment are needed because the load additions impact electrical components differently depending on the equipment's design capacities and existing loading. Naturally, the more numerous and larger the EV circuits installations are, the more frequent and expensive the changes to the building electric infrastructure needed to accommodate them will be.

The other very important item to note here is that these sample calculations are driven from what the demand loads calculated for the building were by the design consultant when it was built (simulated in this example). There is a high probability that the design demand loads used to size the building electrical systems were conservative in nature and therefore demand experienced in the electrical distribution system will be much less than the design values in certain areas.

For exactly that reason, the only realistic method to assess the peak demand experienced by any building or equipment is for qualified firms to measure it for a period of time and then apply engineering judgement to determine what the true base load is. Only by subtracting the measured base load from the equipment capacities at various points in the distribution system can an accurate assessment be made of the unused capacity that exists for uses like EV charging.

The other fundamental point is that plans to add significant loads to existing MURBS should be assessed with the final goals in mind. It is easy to imagine in this hypothetical case that loads are added until the first upgrade step is needed. Then, further loads are added potentially triggering a second, more expensive upgrade higher up the distribution system.

8.4 Demand Control Systems

A demand control system operates by measuring power flows (often with current as a proxy for power) through an electrical distribution system and taking some form of action on a pre-defined set of non-critical loads to keep the power demand in the distribution system below critical threshold values. For EV charging, this would involve actively controlling the number of EV circuits allowed to operate simultaneously and/or the degree of usage of those circuits to keep the total amount of power drawn within an upper limit set by the demand control system.

Demand control schemes are most often used for high power applications in industrial facilities where not exceeding a defined power peak means avoiding very expensive equipment upgrades and/or large penalties on energy and power costs. The systems are not simple and require additional metering, switches, controls and wiring to implement but the net avoided costs justify their expense and maintenance. Demand control systems shut off certain loads or simply turn down large loads to accomplish their goals. Typically, these actions occur with low priority loads being curtailed first and the most valuable controllable loads being affected last. Depending on the level of system sophistication, loads are returned to service either manually or automatically in reverse order to their curtailment sequence when the demand control system assesses capacity exists in the system.

Recall the shape of the typical daily load profile shown in Figure 9. If no controls are in place to limit EV charging, any additional demand loads due to EV charging must be superimposed on the peak of the daily load profile for the purposes of assessing the adequacy of all building electrical system components that have to carry the additional load. Given the daily commuting pattern followed by the bulk of urban dwellers, the tendency will be that EV charging will normally occur when people return from work and will obviously exacerbate the existing evening demand peak in building electrical equipment and, in aggregate, on the complete utility system.

Somewhat differently from industrial demand control systems which curtail a relatively small number of large loads, MURB EV demand control systems may have to control a large number of relatively small loads and incorporate all the logic for prioritization, scheduling and communications such that EVs are available for use charged as needed.

Demand control is rarely seen in residential facilities because the initial design rules are conservative and, normally, there is very little load growth once a residence is occupied. That changes with large scale implementation of EV charging because, as discussed earlier, a portion of the large amounts of energy used for personal transportation are being shifted from the fossil fuel delivery system and routed through building electrical systems.

Demand control to address EV charging is the focus of a large amount of academic and technical study [26] [27] [28] [29] [30] that examines controlled and uncontrolled EV charging in the context of managing effects on local utility distribution systems and on residential building loading. This subject is conceptually well understood however commercial products will only become available as the need for demand control solutions (driven by the number of EV's on the road) aligns with the technological evolution of EVs and emerging smart grid technology.

Interestingly, a locally developed method for EV demand control incorporating networked communications, access to individual EV chargers and the necessity to address both building and utility effects for EVs was described, prototyped and a U.S. patent applied for in 2010 by a member of the Vancouver Electric Vehicle Association (VEVA) [30]

9 EV Charging – Future Impacts on MURB Electrical Systems

9.1 Changes in Regulations

The Canadian Electrical Code rules mandating that EV charging be included at 100% in demand calculations is a conservative, logical first response to ensure that overloading of electrical systems does not occur and the public is protected. As is apparent, having to include the cumulative addition of all EV chargers operating at 100% indefinitely upstream of their individual circuits is conservative but not realistic for two main reasons.

1) Not all vehicles will be connected and begin charging at the same time. While the majority of EV charging in a MURB can be expected to start when commuters return from work, there will be some variation in this that lowers measured additional demand from calculated demand.
2) Not all vehicles will end charging at the same time because of the variation in charger capacities and, most importantly, the EV battery state of charge when charging begins. Most vehicle batteries will not be drained completely and therefore the duration of charging for each vehicle will be unique and much shorter than if the battery was at 0% SOC.

The precedent in the Canadian Electrical Code exists for de-rating other types of time variant loads already such as car plug in heaters so that upstream electrical systems do not have to allow for their full demand loads.

More probable in the short term is that the wording of CEC rule 8-202 (3)(a)(d) may be revised to permit lower than 100% demand for the aggregate of EV charging circuits in a MURB if a demand control system is present. This change has recently appeared in the 2014 version of the American National Electrical Code (NEC) [30] as a modification to existing article 625.41. Paraphrasing, the NEC rule change states that although EV loads must still be considered as continuous, the maximum aggregate demand that a building service entrance or feeder system needs to be sized for due to EV circuits will be the maximum load limit which is set by an automatic load management system.

9.2 Changes in Technology

Much of the back ground information to this point has been provided to show why and how a significant level of EV charging can impact MURB electrical systems. The topic of demand control outlined previously in conjunction with amending the demand regulations is key to making efficient use of building electrical infrastructure.

In any application, good engineering designs are fit for purpose. This design philosophy makes the best use of equipment capacities versus the project capital and financing costs. Over sizing electrical infrastructure for loads that may never occur is wasteful and, in the case of electrical design, can lead to other issues. In power transformer sizing having the rating of the transformer pass a size increment threshold due to provision for EC charging may result in short circuit levels available from the next largest transformer that require more expensive downstream equipment.

The important factor to be aware of is that the electrical industry is steadily making progress on smart grid standards which, in conjunction to the evolving vehicle communications infrastructure inherent in SAE J1772 standards, will create the methodology of using outside signals to actively control the rates of EV on board chargers via local or networked demand control systems.

The technology is not in active use as yet but the pieces of technology necessary have been highlighted in this report. The concept is that sufficient application software and communications will exist in future such that control systems can match available building electrical capacities to aggregate building electrical demands by controlling the charging rates of EV car chargers in real time.

10 Conclusions

Shifting a significant portion of the transportation energy presently used by light duty vehicles from fossil fuel delivery systems to a MURB electrical distribution systems will have significant impact. The magnitude of the impact will be a function of the amount (KW) of transportation energy transferred, how that value relates to the original building electrical design capacity and what the normal or base electrical loading is of the MURB daily and seasonally.

For municipalities following the COV guidelines enacted in 2011, their new MURB buildings contain sufficient capacity for 20% of the assigned parking spaces to be equipped with an EV circuit. There is no set ratio now as to the mix of level 1 versus level 2 circuits that must be incorporated in finished buildings.

The majority of installed circuits in MURB designs and construction projects examined in greater Vancouver for this report have been found to be level 1. This is appropriate because overnight charging at level 1 rates would result in approximately (10 hours x 1.9 KW) = 19 kwhr of energy transfer which would equate to more than 100 km of driving range for commuter EVs such as the Nissan Leaf. Clearly, because the level 2 circuits discussed in this report have an building system electrical impact in proportion to their relative power ratings of 3.5 times that of a level 1 circuit, more level 1 circuits can be made available for the same amount of power in a MURB. While level 2 circuits will be preferred by most for convenience, clearly the impact of widespread level 2 implementation in MURBs carries with it much more potential for significant impact (costs) than does a mix favouring level 1 charging in a strictly residential building.

For retrofit MURBs, the first impact on the building distribution system will generally appear just above the point at which the EV circuits are added but, depending on the load amount, effects may be felt further up the distribution system to the point of the utility entrance.

All building loads are supplied via the local utility distribution system but, due to longer planning and lead times, relatively sudden EV load additions in a local area could create capacity issues in utility neighborhood systems. This is more likely to be the case if high adoption EV rates are coupled with lack of demand control systems and/or other means to control or shift EV charging load so that it does not directly add to the daily early evening demand peak.

Modifications to design rules that regulate how to account for EV loads and implementation of demand control schemes are two methods which have the potential to mitigate electrical impacts on MURBs.

MURB decision makers often face difficult decisions in meeting the expectations of EV adopters in their buildings. This is due to a combination of inexperience with relatively new EV technology and electrical jargon, building electrical system constraints/upgrade costs and the governance issues associated with common areas. While steps are being taken to better understand governance issues locally such as the CHOA sponsored study, the ability of MURB decision makers to control costs of EV implementation and ongoing administration relies first on obtaining appropriate technical guidance on EV charging questions related to their building and also deciding firmly what the limits to EV provisions will be. This is a complex subject and, if the EV installation planned is significant, should involve the original designers of the building, specialist engineering firms or others who can be considered working directly for the MURB owners in order to deliver unbiased advice.

Costs for retrofit EV charging installation work (not including ESVE) is 200 to 300% more expensive as compared to the work being completed as part of new construction. This is due to the practical reality of the installation conditions and differences in cost structure between the two scenarios. This difference should be borne in mind by policy makers who have higher EV adoption rates as a goal when seeking to remove future obstacles to installation.

All work in an existing MURB is unique to some degree. Generally, types of equipment and methods will appear similar but the variations in building layout, existing electrical system loading, preferred parking stalls to provide for, levels of charging needed and particular strata governance rules will make each project unique. Therefore, while guidelines will be useful for strata owners for costing and what to expect typically when undertaking EV additions, they will not remove the need for a facility inspection and study by trained experts if large scale EV additions are desired.

In the foreseeable future, advancing smart grid technology via bi-directional communication with on board EV chargers will create opportunities to control all EV charging in a building to keep below an upper limit, manage sequencing and priority of charging among EVs and allocate EV energy use costs among users. This will require the private sector to develop and deploy innovative systems which may be stand-alone or part of integrated building management systems and that activity will only accelerate as EV adoption rates increase.

Only with real time power measurement to identify building available capacity can the dual goals of managing charging for large numbers of EV's be optimized while making the most efficient use of MURB electrical system capacities and avoiding costly upgrades.

11 Recommendations

1) Modify CEC rule Section 8-202 to reflect changes in EV load treatment where demand control systems exist (similar to that done recently in the NEC).
2) Design a study examining utility billing records, original design data and implement a 1 year energy and power metering program on a sample of small, medium and large MURBs. Compare measured building demand peaks at the incoming building service point, the common area distribution point and at one parking level point versus the distribution system design capacity at those points. Create a baseline of average loading observed versus as-built electrical system capacity in order to understand where problems can be anticipated in typical buildings of those sizes.

From the results of this study, create summary charts of typical “free capacity” versus time for these building types which show the minimum power capacity (KW) that is always available at the building study points. Consider launching this study with industry partners such as those involved in building energy management systems, specialty demand control systems applications and the energy consulting community.

3) Study new small, medium and large size MURB construction and examine the costs of parking EV charging infrastructure installation (raceways) if installed as new construction as compared to a retrofit installation. Assume EV adoption levels of 20, 40 and 60% of parking stalls and compare costs of conduit system installation from the parking stalls back to a central location versus the higher costs if done on a retrofit basis 5, 10 and 15 years in the future and applying the appropriate discount rate for cost comparisons. Engage representatives of the building electrical construction industry to execute the material takeoffs and pricing.
4) Using the representative small, medium and large size MURB facilities in 3), create simple electrical software models for each building type and examine the harmonic impact of combinations of level 1 and level 2 charging operating concurrently on 20, 40 and 60% of parking stalls. The results of this harmonic analysis would be significant to designers in how to group EV loads and may identify the use of isolation transformers as being necessary in some 120/208 volt building designs.

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Academy Multi User Residential Building

Polygon's Academy project located on Berton Avenue at UBC is an 18 storey, 163 suite condominium tower complete with underground parking. The building main electrical room contains an incoming high voltage switch and 1000 KVA 120/208 volt transformer close coupled to a 3000A main distribution switchboard. A 1200A circuit breaker feeds a house distribution switchboard for common loads.

The developer, via the electrical design, has included seven parking stalls on the P2 level which are EV circuit equipped (Figure 1). Four of these designated EV stalls are indicated as 120 volt 20A (1.9 KW Level 1) and the other three are designated as 40A at 208 volts (6.6KW level 2).

A 100 A panel board (Panel EV) is located in a small electrical room immediately behind the wall the outlets are installed on. (Figure 2). A 16 mm conduit extends from panel EV to each of the 120 volt outlets. A 21 mm conduit extends from panel EV to each 208 volt outlet. 4#2 AWG wires in 53 mm conduit run back from panel EV to a 100 A circuit breaker installed in the house portion of the main electrical room 120/208 distribution (Figures 3 & 4) approximately 40 m away.

The four 120 volt EV circuits will be complete with a 20A receptacle. The three level 2 volt circuits will have wires pulled to the parking stall and capped there for future ESVE additions by suite owners. Although limited in terms of circuit capacity and power (7 EV circuits totalling a design demand of 27 Kw in a 163 unit building (approximately 3 % of the main transformer size)) the system will be important for the first building EV users. As the present system is designed around a 100 A breaker, its power rating is approximately (80A x 1.732 x 208V) = 28.8 KW so several system components are essentially at capacity now and an additional EV circuit requirement will trigger component upgrades given existing design rules in force.

Figure 1 - P2 Parking Area Rough In for Seven EV Charging Circuits

Figure 2 - 120/208V Dedicated Parking Panel “EV”

APPENDIX A

Figure 3 - Panel EV 100A Circuit Breaker in Main House Distribution Equipment

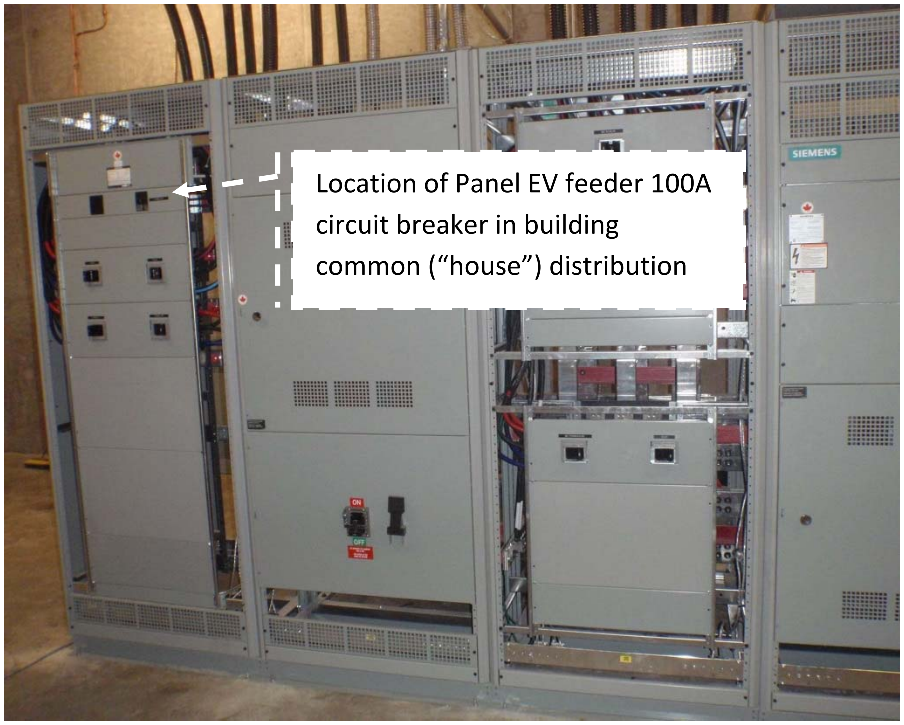


Figure 4 - Main Electrical Room 120/208 V Distribution Switchboard

APPENDIX A

Figure 5 - Main Electrical Room - Incoming Switch and 1000 KVA Transformer

INCREMENTAL EV CHARGING MURB RETROFIT – 6 CASES

Residential Areas Electric Demand Calculations - Generic Condominium Tower - Vancouver B.C.

Area Calculations.	Watts	Canadian Electric Code Demand Calculation Rules
1st 45 sq m	3500	8-202 (a) (i)
2nd 45 sq m	1500	8-202 (a) (ii)
area above 90 sq m	1000	8-202 (a) (iii)
Htg & A/C		8-202 (a) (iv) with demand factor (DF) per section 62 with DF = 100% subject to 8-106(4
Electric Range	6000	8-202 (a) (v) for single rangeplus 40% of any amount the range exceeds 12 KW
Specialty loads		8-202 (vi) (A) 25% of any load in excess of 1.5 KW if an electric range has been 8-202 (vi) (B) as above but with additional 6KW if an electric range has not been

Unit Characteristics		Unit Demand per 8 - 202 (1) (Values in watts)							
Unit Areas - Sq m	# Units	1st 45 m^2	2nd 45 m^2	1st 90 m^2	2nd 90 m@	A/C - Htg	Range	Specialty	Suite Demand
81	20	3500	1500			2400	6000	1500	14900
98	20	3500	1500	1000		2400	6000	1500	15900
105	20	3500	1500	1000		2500	6000	1500	16000
149	20	3500	1500	1000		2600	6000	1500	16100
167	20	3500	1500	1000		3000	6000	1500	16500
204	20	3500	1500	1000	1000	3000	6000	1500	17500
	120								

- 14 Residential Floors
- 6 units per floor
- 84 units total
- All floors same plan

Residential Demand	KW
Fdr#1 - MC#1 & 2	160.1
Fdr#2 - MC#3 & 4	160.1
Fdr#3 - MC#5 & 6	160.1
Fdr#4 - MC#7	80.1
Residential Demand	**560.5**

Meter Center Demand Calc - Fdr 1 - Typical each 24 units

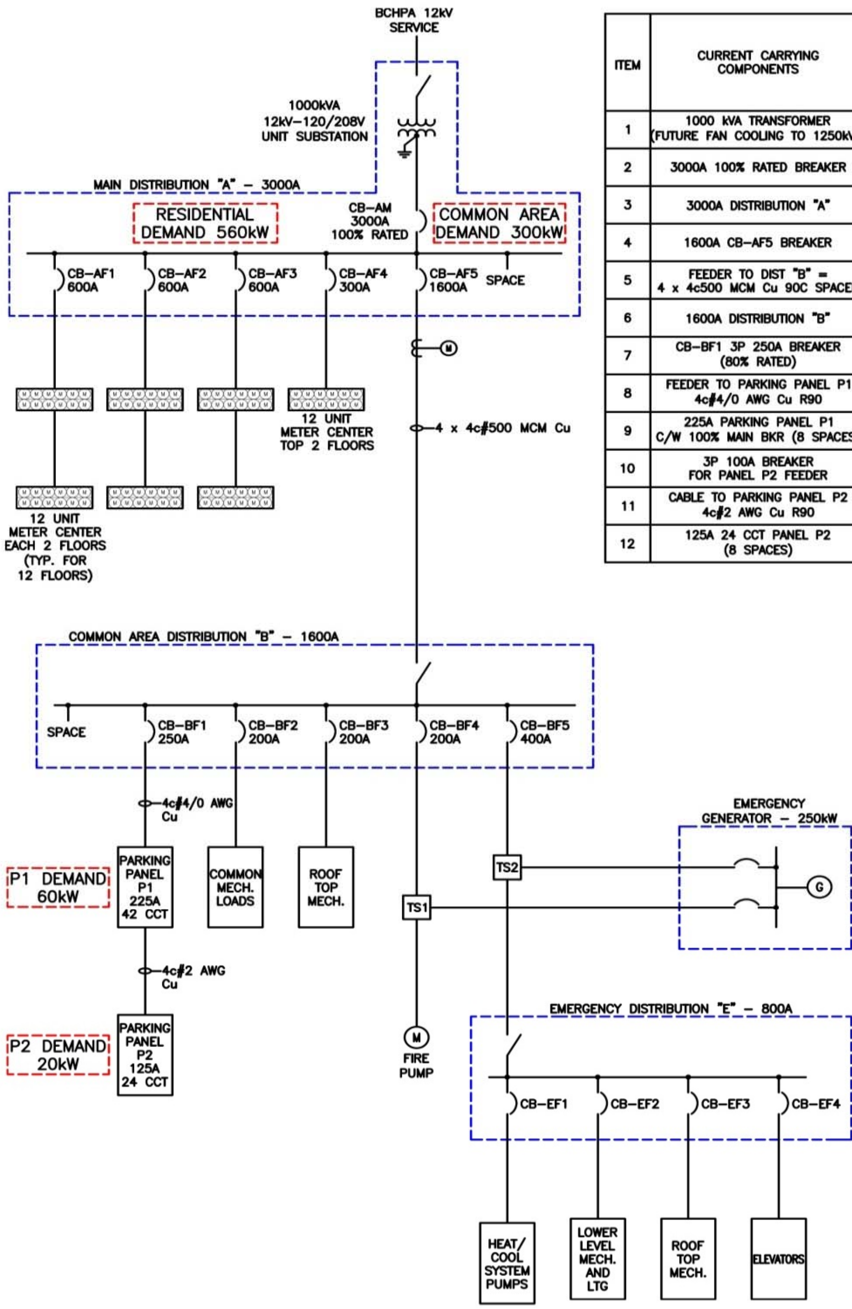
MC#1 - 12 Units	DF (%)	Unit sq m	Unit Demand (W)	KW
Largest	100	204	17500	17.5
Next 2	65	204	17500	11.4
	65	167	16500	10.7
Next 2	40	167	16500	6.6
	40	149	16100	6.4
Next 15	25	149	16100	4.0
	25	105	16000	4.0
	25	105	16000	4.0
	25	98	15900	4.0
	25	98	15900	4.0
	25	81	14900	3.7
	25	81	14900	3.7
		12		80.1
MC#2 - 12 units	**DF (%)**	**Unit sq m**	**Unit Demand (W)**	**KW**
Largest	100	204	17500	17.5
Next 2	65	204	17500	11.4
	65	167	16500	10.7
Next 2	40	167	16500	6.6
	40	149	16100	6.4
Next 15	25	149	16100	4.0
	25	105	16000	4.0
	25	105	16000	4.0
	25	98	15900	4.0
	25	98	15900	4.0
	25	81	14900	3.7
	25	81	14900	3.7
		12		80.1
		24		**160.1**
Demand KW	160.1	2 Meter Centers per feeder		
Assumed PF	0.95	PF estimate		
KVA	168.6	Calc. KVA demand		
A	468	Calc. max demand ampacity @ 3ph 208v		

Figure 1 - Generic MURB Tower - Residential Areas – CEC Section 8 Demand Calculations

Note that this table is intended only to highlight that: 1) the design of the residential portion of building electrical systems is largely rule based on floor area (watts per square meter) plus adding other large electrical loads such as ranges and dryers and 2) there is recognition of time and usage diversity by the design rules (see Demand Factor (DF%)) which reduces the electrical demand impact of additional units as similar units are aggregated. The complete building electrical design incorporates all other electrical equipment generally designated as shared or common plus emergency and specialty loads.

APPENDIX B

This case reflects the demands used at the initial design stage to size the building components and the calculated loading of the power system components.

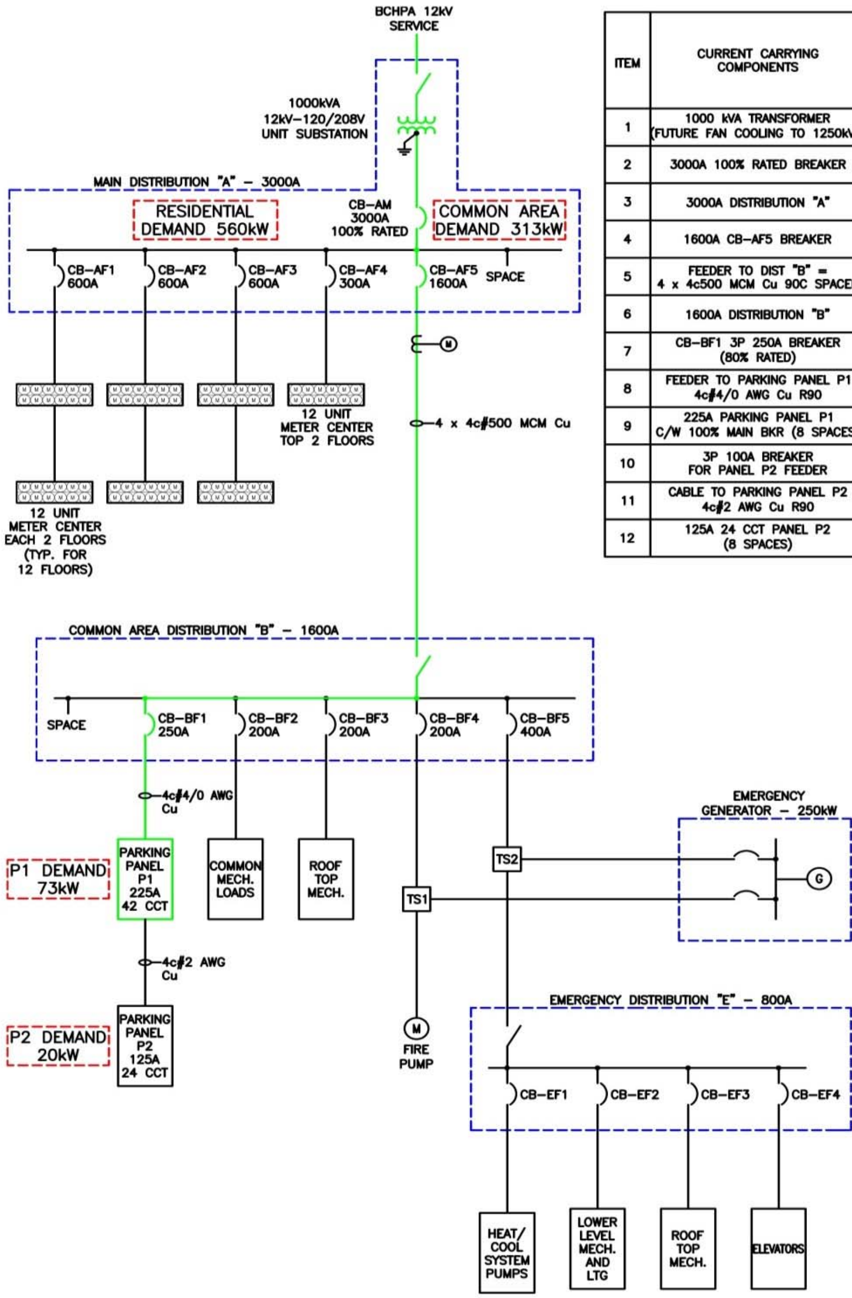


ITEM	CURRENT CARRYING COMPONENTS	CASE 1 – DESIGN CASE			
		EQUIP. RATED CURRENT (A)	DESIGN DEMAND (kW)	DESIGN DEMAND CURRENT (A)	CURRENT AS % OF RATED (A)
1	1000 kVA TRANSFORMER (FUTURE FAN COOLING TO 1250kVA)	2776	860	2513	91%
2	3000A 100% RATED BREAKER	3000	860	2513	84%
3	3000A DISTRIBUTION "A"	3000	860	2513	84%
4	1600A CB–AF5 BREAKER	1280	300	877	68%
5	FEEDER TO DIST "B" = 4 x 4c500 MCM Cu 90C SPACED	1720	300	877	51%
6	1600A DISTRIBUTION "B"	1600	300	877	55%
7	CB–BF1 3P 250A BREAKER (80% RATED)	200	50	146	73%
8	FEEDER TO PARKING PANEL P1 4c#4/0 AWG Cu R90	260	50	146	56%
9	225A PARKING PANEL P1 C/W 100% MAIN BKR (8 SPACES)	225	50	146	65%
10	3P 100A BREAKER FOR PANEL P2 FEEDER	80	20	58	73%
11	CABLE TO PARKING PANEL P2 4c#2 AWG Cu R90	130	20	58	45%
12	125A 24 CCT PANEL P2 (8 SPACES)	100	20	58	58%

CASE 1 – DESIGN CASE - NO EV ADDITIONS

APPENDIX B

This case reflects the addition of the first two level 2 chargers to parking panel P1 (EV power flow shown in green) and the updated calculated values of the power system components relative to their ratings.

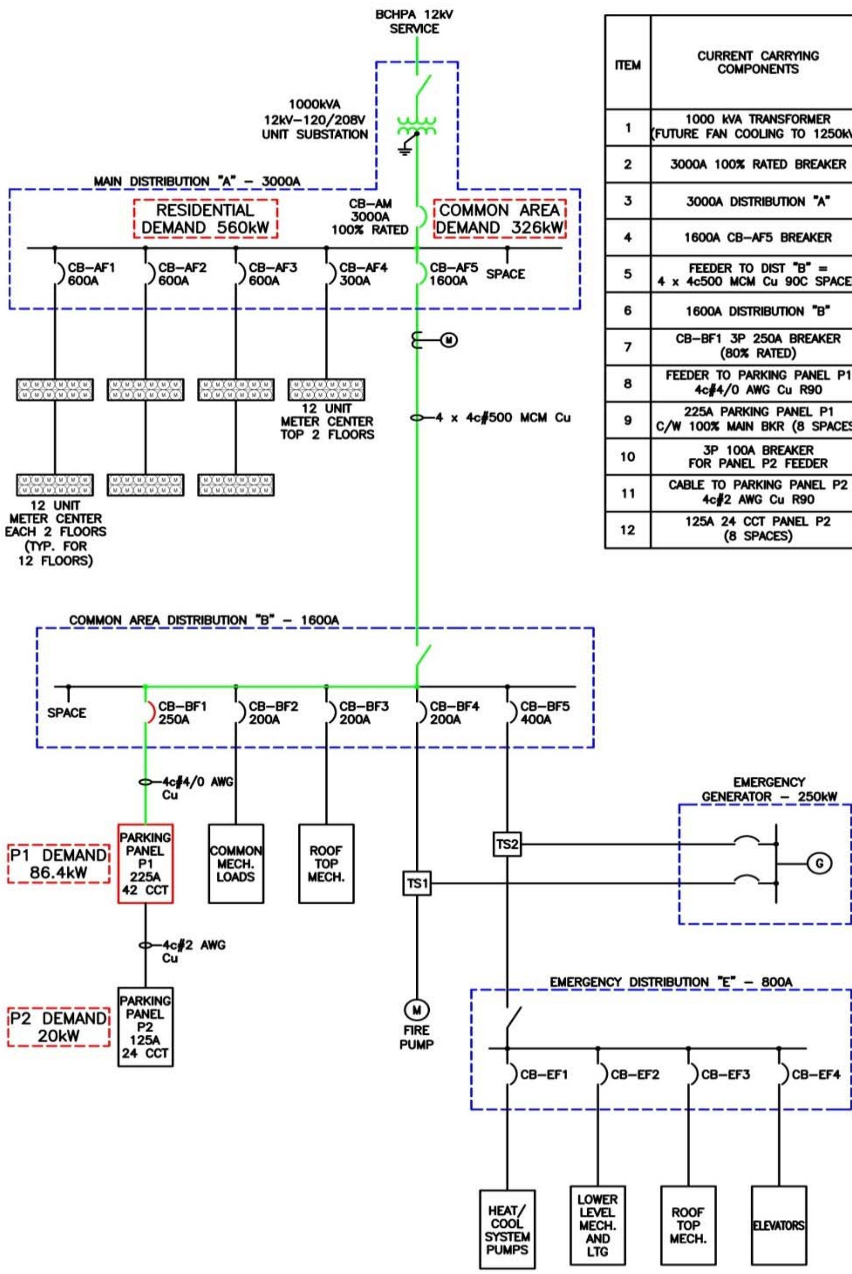


ITEM	CURRENT CARRYING COMPONENTS	CASE 2 – 13.2kW TO PNL P1 (2 x 6.6kW or 7 x 1.8kW)			
		ADDITIONAL CURRENT (A)	EV AS % COMPONENT RATING	NEW CURRENT LOAD (A)	LOAD % OF RATED (A)
1	1000 KVA TRANSFORMER (FUTURE FAN COOLING TO 1250kVA)	39	1.3%	2552	92%
2	3000A 100% RATED BREAKER	39	1.3%	2552	85%
3	3000A DISTRIBUTION "A"	39	1.3%	2552	85%
4	1600A CB–AF5 BREAKER	39	3.3%	916	72%
5	FEEDER TO DIST "B" = 4 x 4c500 MCM Cu 90C SPACED	39	3.0%	916	53%
6	1600A DISTRIBUTION "B"	39	3.3%	916	57%
7	CB–BF1 3P 250A BREAKER (80% RATED)	39	19.5%	185	93%
8	FEEDER TO PARKING PANEL P1 4c#4/0 AWG Cu R90	39	15.0%	185	71%
9	225A PARKING PANEL P1 C/W 100% MAIN BKR (8 SPACES)	39	17.3%	185	82%
10	3P 100A BREAKER FOR PANEL P2 FEEDER	0	0.0%	58	73%
11	CABLE TO PARKING PANEL P2 4c#2 AWG Cu R90	0	0.0%	58	45%
12	125A 24 CCT PANEL P2 (8 SPACES)	0	0.0%	58	58%

CASE 2 ADDITION OF 2 x LEVEL 2 CHARGER CIRCUITS (13.2 KW TOTAL)

APPENDIX B

This case reflects the addition of four level 2 chargers to parking panel P1 (EV power flow shown in green) and the updated calculated values of the power system components relative to their ratings. Clearly overloading occurs in Item 7 and Item 9 is almost overloaded.



ITEM	CURRENT CARRYING COMPONENTS	CASE 3 – 26.4kW TO PNL P1 (4 x 6.6kW or 15 x 1.8kW)			
		ADDITIONAL CURRENT (A)	EV AS % COMPONENT RATING	NEW CURRENT LOAD (A)	LOAD % OF RATED (A)
1	1000 kVA TRANSFORMER (FUTURE FAN COOLING TO 1250kVA)	76	2.5%	2589	93%
2	3000A 100% RATED BREAKER	76	2.5%	2589	86%
3	3000A DISTRIBUTION "A"	76	2.5%	2589	86%
4	1600A CB–AF5 BREAKER	76	6.3%	953	74%
5	FEEDER TO DIST "B" = 4 x 4c500 MCM Cu 90C SPACED	76	5.9%	953	55%
6	1600A DISTRIBUTION "B"	76	6.3%	953	60%
7	CB–BF1 3P 250A BREAKER (80% RATED)	76	38.0%	222	111%
8	FEEDER TO PARKING PANEL P1 4c#4/0 AWG Cu R90	76	29.2%	222	85%
9	225A PARKING PANEL P1 C/W 100% MAIN BKR (8 SPACES)	76	33.8%	222	99%
10	3P 100A BREAKER FOR PANEL P2 FEEDER	0	0.0%	58	73%
11	CABLE TO PARKING PANEL P2 4c#2 AWG Cu R90	0	0.0%	58	45%
12	125A 24 CCT PANEL P2 (8 SPACES)	0	0.0%	58	58%

CASE 3 ADDITION OF 4 x LEVEL 2 CHARGER CIRCUITS (26.4 KW TOTAL)

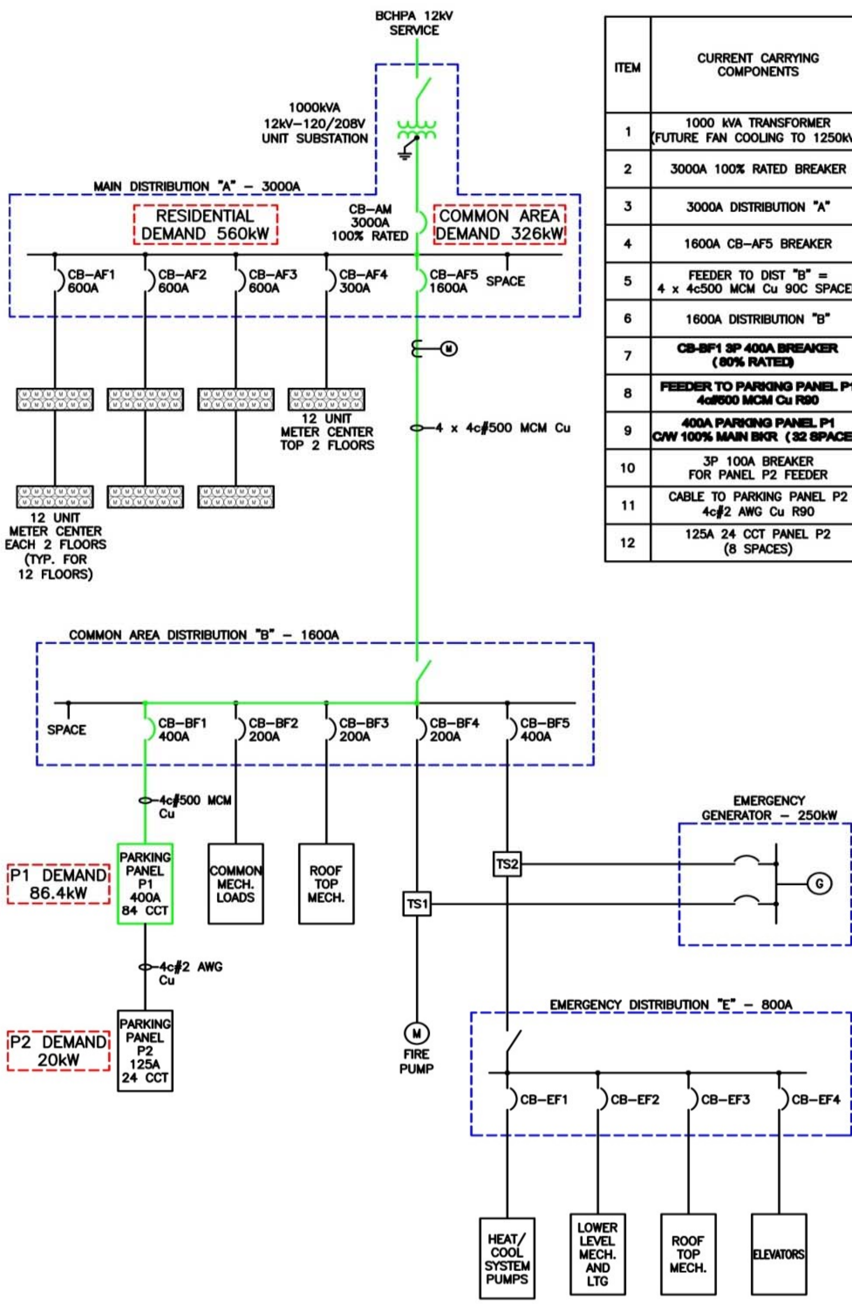
APPENDIX B

This page shows the calculations for for resized components items 7, 8 and 9 as needed to progress from Case 2 to Case 3/3a.

	Lab at service truck rates $/ hr =	$75					
Upgrade Items 7,8 and 9 in report Figure 15. Assumption is that panel P1 is within 30 meters of distribution board B. Feeder upgraded by 2nd parallel 4c#4/0 to be equivalent to 4c#500 MCM as shown in cases.		**Qty**	**Unit**	**Unit Hrs**	**Total Hrs**	**Unit Mtl**	**Total Mtl**
	Shutdown Distribution Board "B" to change breaker	1	lot	2	2.0	$0	$0.00
	Exchange 250 A for 400 A new CB-BF1	1	lot	4	4.0	$2,300	$2,300.00
	63mm EMT conduit surface run	30	m	0.40	12.0	$15	$450.00
	63mm EMT bends	4	ea	1	4.0	$35	$140.00
	#4/0 R 90 wire	140	m	0.04	5.6	$3.75	$525.00
	New 84 cct 400 A panelboard (exhange for old)	1	ea	8	8.0	$2,500	$2,500.00
	Reconnect existing P1 loads and subfeed to P2	1	lot	4	4.0	$15	$15.00
					39.6		$5,930.00
	Material	$5,930					
	Labour	$2,970					
	SUBTOTAL	**8,900**					
	Additional Costs - Allow two floor penetrations	300					
	OH/Profit @ 10%	920					
	TOTAL	**$10,120**					

APPENDIX B

This case reflects the addition of the four level 2 chargers to parking panel P1 (EV power flow shown in green) and the updated calculated values of the power system components relative to their ratings with items 7, 8 and 9 resized and installed.

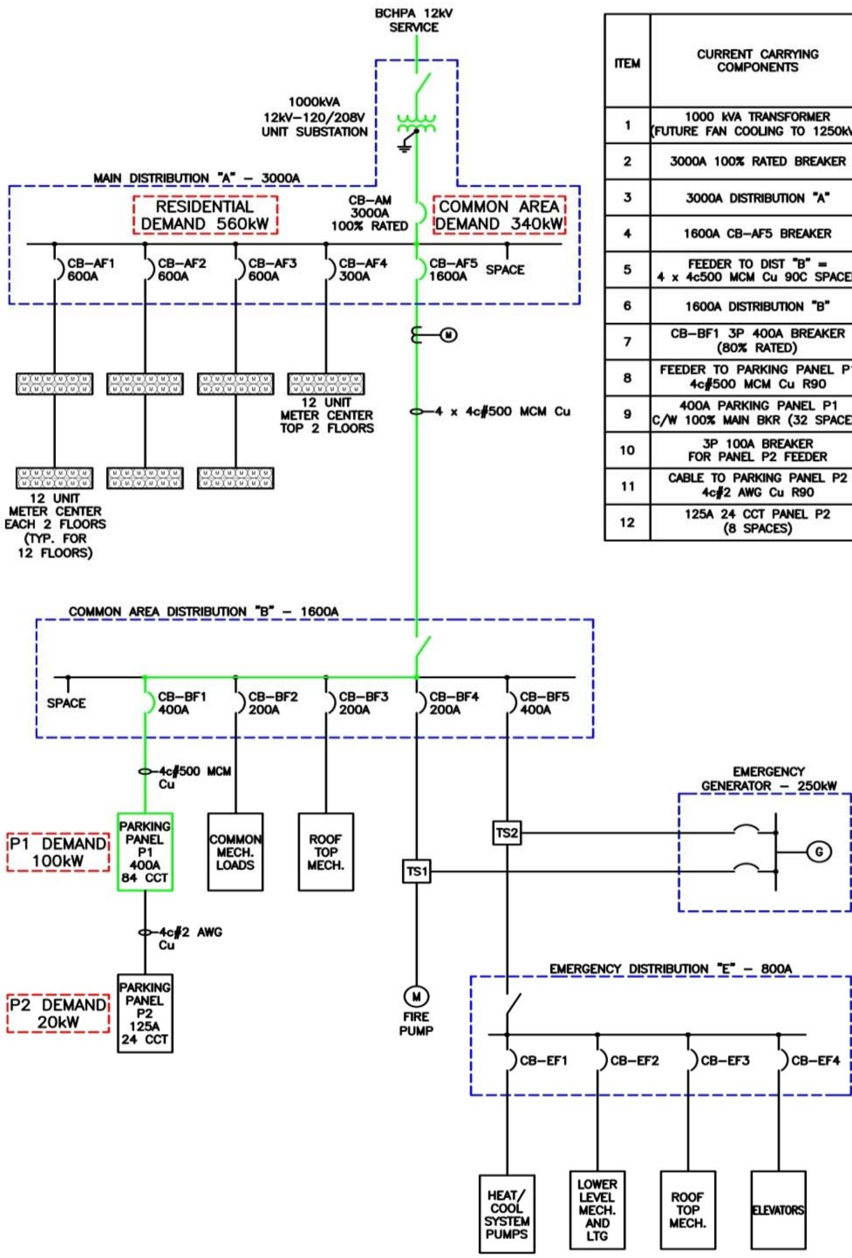


ITEM	CURRENT CARRYING COMPONENTS	CASE 3a – 26.4kW TO PNL P1 (4 x 6.6kW or 15 x 1.8kW)			
		ADDITIONAL CURRENT (A)	EV AS % COMPONENT RATING	NEW CURRENT LOAD (A)	LOAD % OF RATED (A)
1	1000 kVA TRANSFORMER (FUTURE FAN COOLING TO 1250kVA)	76	2.5%	2589	93%
2	3000A 100% RATED BREAKER	76	2.5%	2589	86%
3	3000A DISTRIBUTION "A"	76	2.5%	2589	86%
4	1600A CB–AF5 BREAKER	76	6.3%	953	74%
5	FEEDER TO DIST "B" = 4 x 4c500 MCM Cu 90C SPACED	76	5.9%	953	55%
6	1600A DISTRIBUTION "B"	76	6.3%	953	60%
7	**CB-BF1 3P 400A BREAKER (80% RATED)**	76	23.8%	222	69%
8	**FEEDER TO PARKING PANEL P1 4c#500 MCM Cu R90**	76	17.7%	222	52%
9	**400A PARKING PANEL P1 C/W 100% MAIN BKR (32 SPACES)**	76	19.0%	222	56%
10	3P 100A BREAKER FOR PANEL P2 FEEDER	0	0.0%	58	73%
11	CABLE TO PARKING PANEL P2 4c#2 AWG Cu R90	0	0.0%	58	45%
12	125A 24 CCT PANEL P2 (8 SPACES)	0	0.0%	58	58%

CASE 3a ADDITION OF 4 x LEVEL 2 CHARGER CIRCUITS (26.4 KW TOTAL)

APPENDIX B

This case reflects the addition of six level 2 chargers to parking panel P1 (EV power flow shown in green) and the updated calculated values of the power system components relative to their ratings.

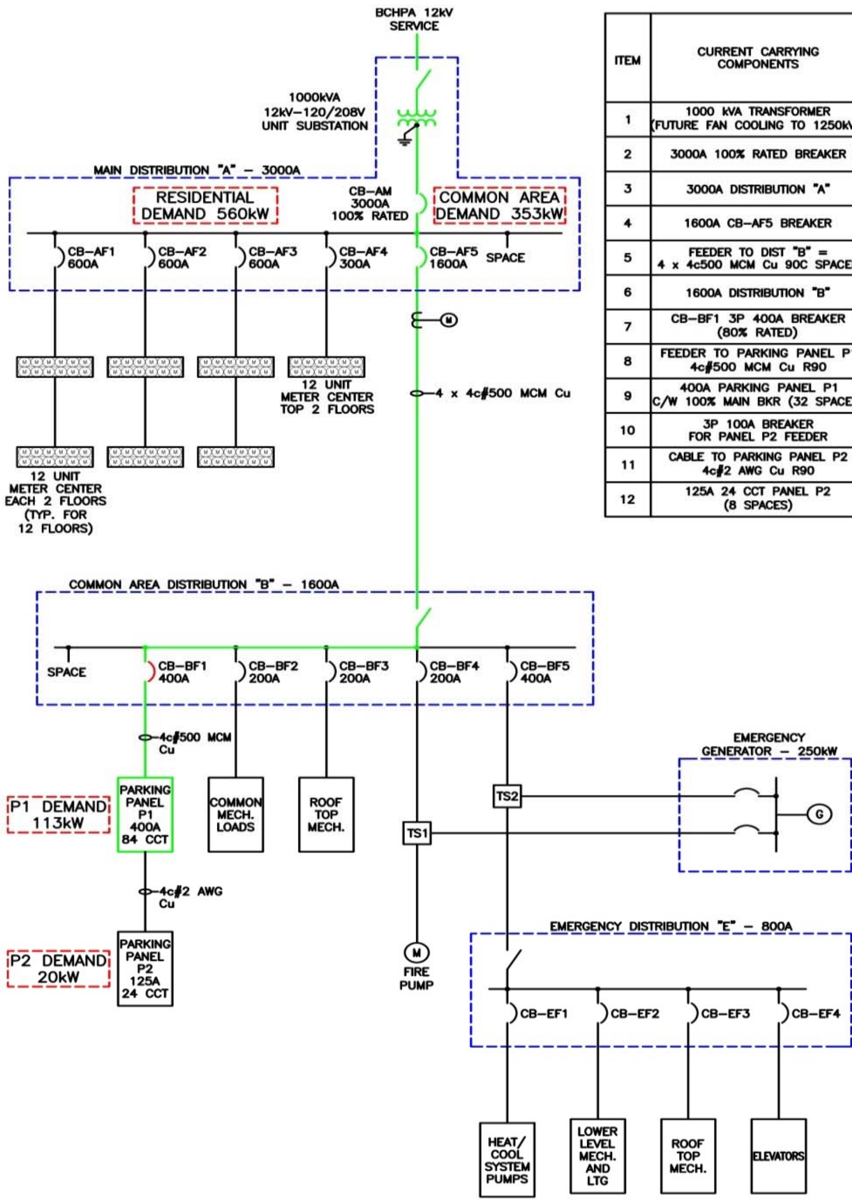


ITEM	CURRENT CARRYING COMPONENTS	CASE 4 – 39.6kW TO PNL P1 (6 x 6.6kW or 22 x 1.8kW)			
		ADDITIONAL CURRENT (A)	EV AS % COMPONENT RATING	NEW CURRENT LOAD (A)	LOAD % OF RATED (A)
1	1000 kVA TRANSFORMER (FUTURE FAN COOLING TO 1250kVA)	116	3.9%	2629	95%
2	3000A 100% RATED BREAKER	116	3.9%	2629	88%
3	3000A DISTRIBUTION "A"	116	3.9%	2629	88%
4	1600A CB–AF5 BREAKER	116	9.7%	993	78%
5	FEEDER TO DIST "B" = 4 x 4c500 MCM Cu 90C SPACED	116	7.0%	993	58%
6	1600A DISTRIBUTION "B"	116	9.7%	993	62%
7	CB–BF1 3P 400A BREAKER (80% RATED)	116	36.3%	262	82%
8	FEEDER TO PARKING PANEL P1 4c#500 MCM Cu R90	116	27.0%	262	61%
9	400A PARKING PANEL P1 C/W 100% MAIN BKR (32 SPACES)	116	29.0%	262	66%
10	3P 100A BREAKER FOR PANEL P2 FEEDER	0	0.0%	58	73%
11	CABLE TO PARKING PANEL P2 4c#2 AWG Cu R90	0	0.0%	58	45%
12	125A 24 CCT PANEL P2 (8 SPACES)	0	0.0%	58	58%

CASE 4 ADDITION OF 6 x LEVEL 2 CHARGER CIRCUITS (39.6 KW TOTAL)

APPENDIX B

This case reflects the addition of eight level 2 chargers to parking panel P1 (EV power flow shown in green) and the updated calculated values of the power system components relative to their ratings.



ITEM	CURRENT CARRYING COMPONENTS	CASE 5 – 52.8kW TO PNL P1 (8 x 6.6kW or 29 x 1.8kW)			
		ADDITIONAL CURRENT (A)	EV AS % COMPONENT RATING	NEW CURRENT LOAD (A)	LOAD % OF RATED (A)
1	1000 kVA TRANSFORMER (FUTURE FAN COOLING TO 1250kVA)	154	5.1%	2667	96%
2	3000A 100% RATED BREAKER	154	5.1%	2667	89%
3	3000A DISTRIBUTION "A"	154	5.1%	2667	89%
4	1600A CB–AF5 BREAKER	154	12.8%	1031	81%
5	FEEDER TO DIST "B" = 4 x 4c500 MCM Cu 90C SPACED	154	11.9%	1031	60%
6	1600A DISTRIBUTION "B"	154	12.8%	1031	64%
7	CB–BF1 3P 400A BREAKER (80% RATED)	154	48.1%	300	94%
8	FEEDER TO PARKING PANEL P1 4c#500 MCM Cu R90	154	35.8%	300	70%
9	400A PARKING PANEL P1 C/W 100% MAIN BKR (32 SPACES)	154	38.5%	300	75%
10	3P 100A BREAKER FOR PANEL P2 FEEDER	0	0.0%	58	73%
11	CABLE TO PARKING PANEL P2 4c#2 AWG Cu R90	0	0.0%	58	45%
12	125A 24 CCT PANEL P2 (8 SPACES)	0	0.0%	58	58%

CASE 5 ADDITION OF 8 x LEVEL 2 CHARGER CIRCUITS (53 KW TOTAL)

New versus Retrofit Calculations – (Report Section 8.1)

This estimate indicates reasonable ranges of differences between new construction and retrofit construction for a level 1 and a level 2 EV charging circuit. The differences revolve around economies of scale in material costs, labour efficiency, labour costs, construction conditions (obstacles encountered during installation) and overhead and profit levels required to engage in business.

For retrofit versus new construction (personal approximations used only); material costs are higher (20%), labour efficiency is lower (20%), labour costs are higher (50%), other costs for specialty equipment or services are much more likely to be needed and charged to the job (i.e.: hole coring), and the company overhead and profit is required to be higher to account for the higher operating costs on small jobs i.e.: service trucks, office staff costs etc.

New	Const Lab @ $/hr	50
Retro	Service Lab@$/hr	75

NEW @120V Level 1	1 x 120V, 20A - 25 m linear distance, same floor level, electrical room access costs not applicable as electricians present as building constructed.	Qty	Unit	Unit Hrs	Total Hrs	Uni Mtl	Total Mtl
	- 19 mm EMT conduit - surface run	30	m	0.16	4.8	$2.05	$61.50
	- #12 AWG wire	65	m	0.007	0.5	$0.40	$26.00
	- 15A 120 volt CB	1	ea	0.50	0.5	$15.00	$15.00
	- Outlet box c/w 20 A receptacle	1	ea	0.75	0.8	$15.00	$15.00
					6.5		$117.50
	Material	$118					
	Labour	$325					
	SUBTOTAL	**443**					
	Additional Costs	0					
	OH/Profit @ 5%	22					
	TOTAL	**$465**					

RETRO @120V Level 1	1 x 120V, 20A - 25 m linear distance, same floor level, electrical room access costs required as electricians not present as building constructed.	Qty	Unit	Unit Hrs	Total Hrs	Uni Mtl	Total Mtl
	- 19 mm EMT conduit - surface run	30	m	0.20	6.0	$2.50	$75.00
	- #12 AWG wire	65	m	0.010	0.7	$0.48	$31.20
	- 15A 120 volt CB	1	ea	0.50	0.5	$17.50	$17.50
	- Outlet box c/w 20 A receptacle	1	ea	0.75	0.8	$17.50	$17.50
					7.9		$141.20
	Material	$141					
	Labour	$593					
	SUBTOTAL	**734**					
	Additional Costs - 2 wall penetrations @ $150 each	300					
	OH/Profit @ 10%	103					
	TOTAL	**$1,137**					

NEW @208V Level 2	1 x 208V 40A - 25 m linear distance, same floor level, electrical room access costs not applicable as electricians present as building constructed.	Qty	Unit	Unit Hrs	Total Hrs	Uni Mtl	Total Mtl
	- 21 mm EMT conduit - surface run	30	m	0.20	6.0	$3.02	$90.60
	- #8 AWG wire	65	m	0.011	0.7	$1.15	$74.75
	- 40A 208 volt CB	1	ea	0.75	0.8	$30.00	$30.00
	- Outlet box	1	ea	0.75	0.8	$5.00	$5.00
					8.2		$200.35
	Material	$200					
	Labour	$411					
	SUBTOTAL	**611**					
	Additional Costs	0					
	OH/Profit @ 5%	31					
	TOTAL	**$642**					

RETRO @208V Level 2	1 x 208V 40A - 25 m linear distance, same floor level, electrical room access costs not applicable as electricians present as building constructed.	Qty	Unit	Unit Hrs	Total Hrs	Uni Mtl	Total Mtl
	- 21 mm EMT conduit - surface run	30	m	0.25	7.5	$3.60	$108.00
	- #8 AWG wire	65	m	0.014	0.9	$1.38	$89.70
	- 40A 208 volt CB	1	ea	1.00	1.0	$35.00	$35.00
	- Outlet box	1	ea	1.00	1.0	$6.00	$6.00
					10.4		$238.70
	Material	$239					
	Labour	$781					
	SUBTOTAL	**1,019**					
	Additional Costs - 2 wall penetrations @ $150 each	300					
	OH/Profit @ 10%	132					
	TOTAL	**$1,451**					