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# Electric Vehicle Energy Management Systems

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# Executive Summary

Electrification of transportation is a prerequisite to achieving greenhouse gas emissions reduction targets and sustainability goals established under the Paris agreement on climate change and the Pan-Canadian Framework on Clean Growth and Climate Change. Canada's commitment is to reduce greenhouse gas emissions to 30% below 2005 levels, by 2030.

To accommodate and encourage electric vehicles (EVs) adoption, extensive charging infrastructure installation is necessary. Electric vehicle power requirements are significant. In simplest terms, the objective represents replacing energy consumed by internal combustion engine (ICE) vehicles with electricity sourced from building electrical systems and utility grids. Such a transformation represents a considerable challenge, as building electrical systems and utility grids were not designed to accommodate the magnitude and acceleration of electrical load increases.

Existing buildings have a fixed capacity in accordance with design requirements at the time of construction, which do not include support for EV charging. The majority of existing buildings have insufficient capacity to accommodate the electrical load of uncontrolled EV charging.

Electric vehicle energy management systems (EVEMS) represent an opportunity to maximize usage efficiency of existing electrical infrastructure and avoid prohibitive costs inherent with capacity upgrades.

EVEMS technologies are in relative infancy, having only been recognized in the 2018 edition of the *Canadian Electrical Code* (CSA C22.1-18, *Canadian Electrical Code, Part I;* 24th Edition). A significant barrier to adoption of these technologies is the absence of a relevant product (*Canadian Electrical Code,* Part II) standard in Canada. Without a product standard, there exists no basis for testing and certification. Subsequently, no products are certified for use in Canada. A number of electrical safety authorities have developed variance processes to permit installation of a small number of products. However, these efforts represent an interim measure until a product standard is developed and testing and certification laboratories have a basis for certification.

The following report provides details of EVEMS configurations and control schemes with particular attention on time allocation and power allocation with noted advantages and disadvantages in support of the subsequent development of a product standard.

In conclusion, the three variations of load management with monitoring are the schemes that achieve greatest utilization efficiency of electrical infrastructure, and following logical conclusions, provide the most probable long-term solution for EV charging.

# 1 Introduction

Electric vehicles (EVs) were introduced in the mid-19th century, but forfeited commercial viability to internal combustion engine (ICE) vehicles. This was due to the energy density advantage of gasoline compared to battery technology at the time. In the past decade, EVs have experienced a resurgence, motivated by environmental concerns and assisted by advancements in battery technology.

In North America, SAE International[1] developed a standard for EV charging. In 2009, the organization released the recommended practice, *SAE Surface Vehicle Recommended Practice J1772, SAE Electric Vehicle Conductive Charge Coupler,* which was revised in 2016 and 2017 and is currently titled, S*AE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler* [1]. SAE J1772 specifies functional and performance requirements for electric vehicle supply equipment (EVSE)[2] and describes electrical and physical interfaces between vehicles and EVSE, including the connector for Level 2 charging, which utilizes nominal supply voltages of 208 and 240 volts.

Other standards on EV charging have been developed, including but not limited to the IEC 61851 series, *Electric Vehicle Conductive Charging System* [2], and UL 2202, *Standard for Electric Vehicle (EV) Charging System Equipment* [3]. CSA Group, in collaboration with UL and ANCE, have also published four tri-national standards relevant to EVSE:

- NMX-J-677-ANCE/C22.2 No. 280-16/UL 2594: *Electric vehicle supply equipment* [4],
- NMX-J-678-ANCE/C22.2 No. 282-17/UL 2251: Plugs, receptacles, and couplers for electric vehicles [5],
- NMX-J-668/1-ANCE/C22.2 No. 281.1-12/UL 2231-1: *Standard for safety for personnel protection systems for electric vehicle (EV) supply circuits: General requirements* [6], and
- NMX-J-668/2-ANCE/C22.2 No. 281.2-12/UL 2231-2: *Standard for safety for personnel protection systems for electric vehicle (EV) supply circuits: Particular requirements for protection devices for use in charging systems* [7].

As the number of EVs increase, so does the necessity for additional EVSE, and subsequently, increased electrical infrastructure capacity. However, existing electrical infrastructure was not designed to accommodate EV charging. In urban areas, many people live in multi-unit residential buildings (MURB), such as apartments and condominiums with associated parking garages. Residents in these buildings require access to charging, but incoming electrical supplies, transformers, electrical panels, and feeders typically have insufficient spare capacity to accommodate dedicated EVSE for each parking stall. A potential solution to this limitation is implementing electric vehicle energy management systems (EVEMS) to maximize electrical infrastructure utilization to accommodate as many EVSE as possible.

EVEMS offer a compromise between charging performance and cost on the assumption that the average driver does not require 300 km of range per day.

Virtually all EVs sold in the North American market have a SAE J1772 charging port.[3] As such, the focus of this report is on Level 2 charging infrastructure and, specifically EVEMS. While many EVs also include a DC (direct current) fast charger port, this is outside the scope of this report.

The 2018 edition of the Canadian Electrical Code (CSA C22.1-18 *Canadian Electrical Code, Part I;* 24$^{th}$ Edition) [8] recognizes technology advancements and allows for EVEMS. Rule 8-002 defines EVEMS as, "a means used to control electric vehicle supply equipment loads through the process of connecting, disconnecting, increasing or reducing electric power to the loads and consisting of any of the following: a monitor(s), communication equipment, a controller(s), a timer(s),

[1] Originally established as the Society of Automotive Engineers, SAE International is a United States-based global standards development organization for engineering professions.

[2] Chargers are assigned the term (EVSE), which has been adopted by various codes and standards, including those of CSA Group.

[3] Tesla provides an adapter that supports connection to a SAE J1772.

and other applicable device(s)." Additionally, Rule 8-500 addresses installation of EVSE where an EVEMS is installed.

However, there is currently no comprehensive product standard to specify functional and performance requirements, marking, and testing for EVEMS or EVSE controlled by EVEMS. Further, there does not appear to be standards for EVEMS in other countries and jurisdictions. This report provides an overview of EVEMS configurations and control schemes to assist in efforts to address the issue and offers recommendations for content inclusions in a standard.

# General

## 1 Methods

The methods used to prepare this report included

- a review of academic and grey literature;
- industry reports;
- review of EVEMS standards in Canada and other countries;
- discussions with vendors;
- consultation with engineering firms;
- work with Technical Safety BC on a variance process;
- research of variance processes in other jurisdictions;
- experience on EVEMS design and construction projects; and
- consultation with the advisory panel.

## 2 Definitions

An EVEMS standard has not been developed thus far. As such, defined terms for EVEMS control configurations and schemes could not be found in the literature. The term "EVEMS" was only recently introduced in the 2018 edition of the *Canadian Electrical Code* [8].

The following definitions will be used as a basis for description and assessment in subsequent sections.

Energy management: Control of the current drawn by EVSE.

Energy management schemes: Pertains to the manner power is allocated. Basic schemes include:

- Time allocation;
- Power allocation, which can be further sub-categorized as;
  - Load switching;
  - Load sharing;
  - Load management without monitoring;
  - Load management with EVSE monitoring;
  - Load management with external monitoring; and
  - Load management with monitoring at EVSE and external.

## 3 EVEMS Control Schemes

There are currently several products in the marketplace that fall under the general category of EVEMS. EVEMS are also referred to as "demand charge controllers for electric vehicles" and "load managed" EV chargers, which can lead to confusion as to what exactly is meant by EVEMS. Since there are different approaches to EVEMS, it is useful to consider these approaches separately, as the specific approach affects safety-testing considerations for the products. There are two main categories of EVEMS control schemes, namely "time allocation" and "power allocation", which Sections 3.1 and 3.2 describe in more detail below.

### 3.1 Time Allocation

#### *3.1.1 Overview*

The time allocation (TA) scheme (also called "rotational charging") is the assigning of power to EVSE based on time. Power is supplied to one or more chargers for a time period, and then reallocated to the next EVSE(s). Several strategies exist to optimize this process, such as turning on a charger and then cycling to the next charger if no power is consumed within a short time. Such systems typically do not include communications with EVSE. This approach is used for block heaters in cold climates, as per CSA C22.1-18, *Canadian Electrical Code, Part I,* Rule 8-400.

*"Time allocation scheme: Power is supplied to one or more chargers for a time period, and then reallocated to the next EVSE(s)."*

#### *3.1.2 Possible Configurations*

The industrial controls sector employs a strategy using relays in a panel that switch dedicated circuits on or off, an approach that is also used in lighting controls. One electrical utility considered an approach using a timer in conjunction with streetlights to turn EVSE on and off based on streetlight timing.

#### *3.1.3 Advantages*

The advantages of time allocation include simplicity and the ability to operate with any EVSE not impacted by regular input power switching. It can also be used to schedule charging to avoid demand charges and reduce supply and feeder sizes. The approach has the potential for long-term parking and large fleets, where immediate access to charging is unnecessary. The systems typically avoid service fees.

#### *3.1.4 Disadvantages*

The majority of EVSE are not designed to withstand or operate correctly with regular input power switching. Many products' warranties would be voided under such conditions, and the components would be subjected to conditions that impact operational life. Many EVSE are designed with a random delay to ensure that charging does not commence immediately when power is restored. This feature is incorporated to avoid the inrush associated with major step-load changes and inherent strains on electrical systems, including the utility grid. The delay represents time when no charging occurs, thereby reducing charging performance. This is a situation the controller is unable to recognize and respond to accordingly.

Power switching also creates potential problems for the EV, because each time power is cycled, the vehicle records the event as a separate charging session. Each charging session exercises DC contactors for the battery, which may cause warranty issues or reduced operational life. In addition, an email notice may be sent each time charging ends, generating nuisance emails.

The approach is also contrary to the influence of the Internet of Things (IoT) and smart building technologies, with devices communicating and intelligently achieving optimum results. With no communications between EVEMS and EVSE, there is also no method of identifying or reacting to a defective EVSE.

Due to these disadvantages, load switching is not anticipated to represent a viable long-term control scheme, except in single-family dwellings.

#### *3.1.5 Specific Safety Considerations*

There are safety concerns with the time allocation approach to EVEMS. In a particular approach where existing street light infrastructure was utilized to install EVSE, a timer was considered to turn EVSE on and off with the streetlights. In this case, a photocell controlled the streetlights. This was problematic, as a potential for fire exists if a photocell fails or if heavy overcast conditions cause the streetlights to come on outside of the typical lighting time window. In such instances, the timer would allow EVSEs to energize at the same time, thereby overloading the circuit.

If a timer approach is used, the timer should control all the loads on the circuit that could potentially result in an overload. In the example above, a timer would need to control both the streetlights and the EVSE to ensure only one of those two loads were serviced at a particular time. Time-based switching is permitted in the Canadian Electrical Code 2015, Section 86, which is adopted in most provinces. However, the operational issues noted above are not tested for in CSA C22.2 No. 280-16, which depend on the vehicle responding correctly.

Due to the disadvantages listed above, time allocation is not recommended as a viable approach to EVEMS.

## 3.2 Power Allocation

### *3.2.1 Overview*

The power allocation (PA) approach uses various methods to limit or stop current flow to one or more EVSE. These include

- Load switching;
- Load sharing;
- Load management without monitoring;
- Load management with EVMS monitoring;
- Load management with external monitoring; and
- Load management monitoring at EVMS and external.

In the simplest examples of PA, a single breaker protects two EVSE, and when one EVSE is in use, it signals to the other EVSE (usually through a hardwired connection) that it is only allowed to offer 50% of the power that it normally offers. When the second EVSE detects a vehicle is ready to charge, it signals the first EVSE that it must also only offer 50% of the power it normally provides before it closes its contactor. This effectively splits the power between the two vehicles. The limit is assured by the hardwired connection. This is similar to the way "power shared" dual-headed stations can operate.

More complex power allocation systems can use the "current offered" to the vehicles to calculate the expected load on breakers that service only managed EV charging loads. Using this method, the EVEMS can track several EVSEs across multiple breakers and panels. To properly limit the power effectively, the EVEMS must be configured to understand the electrical structure of the building. Electrical meters can be added into the electrical system to monitor consumption at each EVSE or any circuit within the building. Electrical meters can help the EVEMS correct the calculated "current offered" into "power consumed", and potentially enable better utilization of the available power across several circuits.

An advanced EVEMS can accept additional limits to restrict the available power in the system. These limits could be from a building automation system or from an external source, such as the utility, to restrict EV charging during a "critical peak pricing event" or in response to "time of use" pricing. If these signals are utilized, the EVEMS would not be able to exceed the circuit demand rating at any time.

The SAE J1772 protocol requires that the EVSE continuously send a pulse wave modulation (PWM) signal to the vehicle. This PWM signal specifies the amount of power that the electric vehicle is permitted to draw. Traditionally this signal was not adjustable, but rather was set to match the breaker/contactor/wire size that the EVSE was designed for. With modern controllable EVSEs that allow spontaneous alteration of this PWM signal, limits should exist that prevent the EVSE from advertising a maximum current that would exceed the breaker/contactor/wire size limits of the physical device.

It is useful to consider specific examples of power allocation in more detail below.

### *3.2.2 Load Switching*

#### 3.2.2.1 Overview

A load switching approach uses an EVEMS specially designed to allow the connection of an EVSE to a panel or circuit that is at full capacity and would otherwise require a service upgrade. This approach requires current transformers (CTs) to be installed on the building electrical panel. CTs provide real-time reading of a panel's total power consumption and detect when total power consumption exceeds a fixed amount of available capacity. This threshold represents a percentage of the main breaker in the panel. When the threshold is reached, the EVEMS temporarily de-energizes the EVSE. As the total power consumption of building panel drops below the defined threshold and remains at that capacity for a period of time, the EVEMS acts to re-energize the EVSE.

Load switching approaches typically use a contactor(s) on the circuit(s) to the EVSE(s), whereby the contactor(s) switch all of the EVSEs on or off together. Load switching appears to be mainly targeted to a single EVSE in a residential setting.

Figures 1 and 2 below show two different CT configurations that can be used in conjunction with load switching – one with the CT installed at the feed to the electrical panel, and one with the CT integrated into the EVEMS.

#### 3.2.2.2 Advantages

The load switching approach to EVEMS has the advantage of simplicity in that it can accommodate EVSE loads that would not otherwise be supported without upgrades to panels and/or electrical services. The systems also typically avoid service fees.

#### 3.2.2.3 Disadvantages

There are several disadvantages to the load switching approach:

- first, this approach is only suitable for one EVSE per electrical panel and, therefore, is not scalable.
- second, some vehicles will not resume charging after power is restored to the EVSE.
- third, if the panel is close to its limits, the EVSE may turn off quite often.

This approach also has the same disadvantage as time allocation, including warranty implications, the possibility that vehicles will not resume charging, and premature wear of contactors.

***Figure 1:*** *Single Family Home Load Switching*

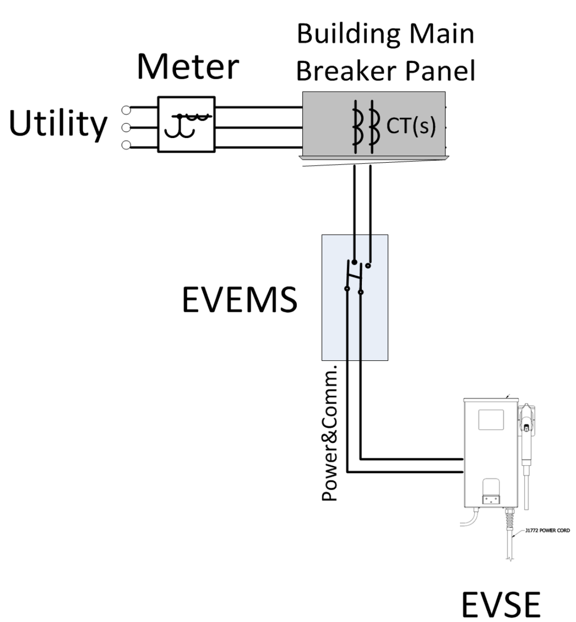
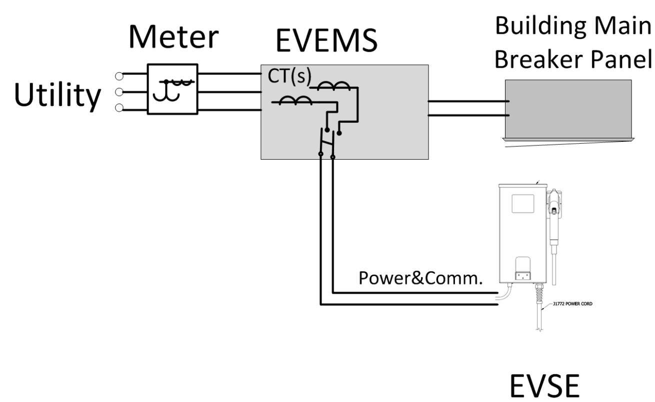



***Figure 2:*** *MURB Load Switching*



#### 3.2.2.4 Specific Safety Considerations

There are some safety considerations with the load switching approach to EVEMS. In cases where CTs are external to the EVEMS, the connection to the CT could be severed, halting information flow on power consumption to the EVEMS. In such a situation, the EVEMS unit may offer power to the EVSE when the panel is overloaded. Some detection may be needed by the EVEMS unit to detect false 0 Amp readings.

Due to the disadvantages and safety considerations listed above, load switching is not recommended as a viable approach for EVEMS.

### *3.2.3 Load Sharing*

#### 3.2.3.1 Overview

A load sharing approach to charging control is based on allocating equal power across all EVSEs that are connected to one branch circuit. For example, one particular vendor's EVSE consists of two charge units, each with a single EV connector. The two units are typically fed by a 40 A circuit, and each unit is capable of drawing 32 A. If only one EV is connected, that EVSE unit is capable of supplying the full 32 A. If two EVs are connected, power is shared between the two units, and each would be capable of supplying a maximum of 16 A, or 50% of the available 32 A. If the EVSE does not have integrated metering, it may be necessary for the EVEMS to monitor the current on the breakers to ensure the breaker limit is never exceeded.

Another vendor's EVSE also uses this approach, but the two charge units are integrated into a single enclosure.

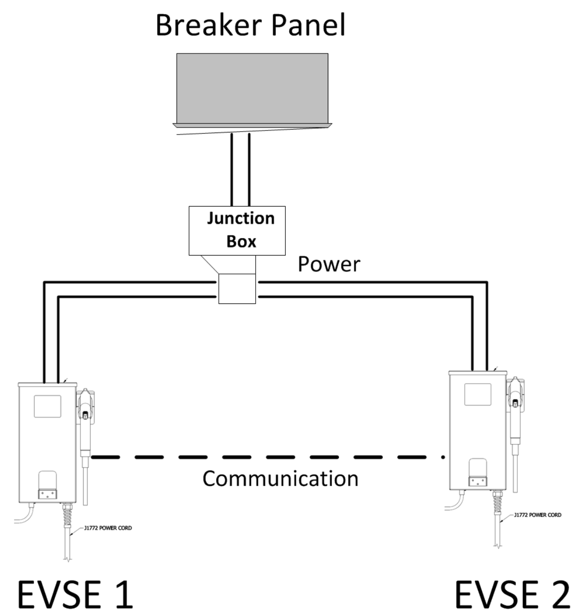
#### 3.2.3.2 Advantages

This power allocation scheme represents a simple approach that is typically selected for small-scale installations. Advantages include reduced installation costs, reduced capacity requirements, design simplicity, ease of system setup, and avoidance of service fees.

#### 3.2.3.3 Disadvantages

The load sharing approach is less efficient compared to load management systems with monitoring capabilities, as there is often a reduction in the utilization of available

***Figure 3:*** *Load Sharing*




| If EVSE 1 | Then EVSE 2 |
|---|---|
| 100% | 0 |
| 50% | 50% |
| 0 | 100% |

power. For example, many vehicles reduce power consumption as the battery approaches a full charge. In such a situation, one vehicle may not draw the full percentage of power it is allocated, but the other connected vehicle would not be able to take advantage of the unused power allocation of the first vehicle.

#### 3.2.3.4 Specific Safety Considerations

Load sharing approaches for EVEMS may present safety considerations that could result in circuit overloading. One possible circumstance includes the EV overriding the EVSE limit and using more current than the EVSE is advertising, causing the breaker to trip. One particular vendor has found one pre-production vehicle that would pull more current than the EVSE was advertising, however none of the production vehicles are known to cause this problem.

In the case of one vendor's EVSE, if the hard-wire connection between the two EVSEs fails or is severed,

*"The load management without monitoring approach is based on set power allocations to each EVSE for a specified period of time."*

then both EVSEs will offer full power to both vehicles instead of going to fail-safe mode, thereby disconnect power to the EV.

Finally, hobbyist solutions have been developed to provide the appropriate signals to the SAE J1772 charging port to cause the contactors to close. Typically, these solutions have a SAE J1772 receptacle on one side and a NEMA 6-50 receptacle on the other. This hobbyist solution can provide power to any device, not just a SAE J1772 electric vehicle. These devices will not respect the limits of the EVEMS.

### *3.2.4 Load Management without Monitoring*

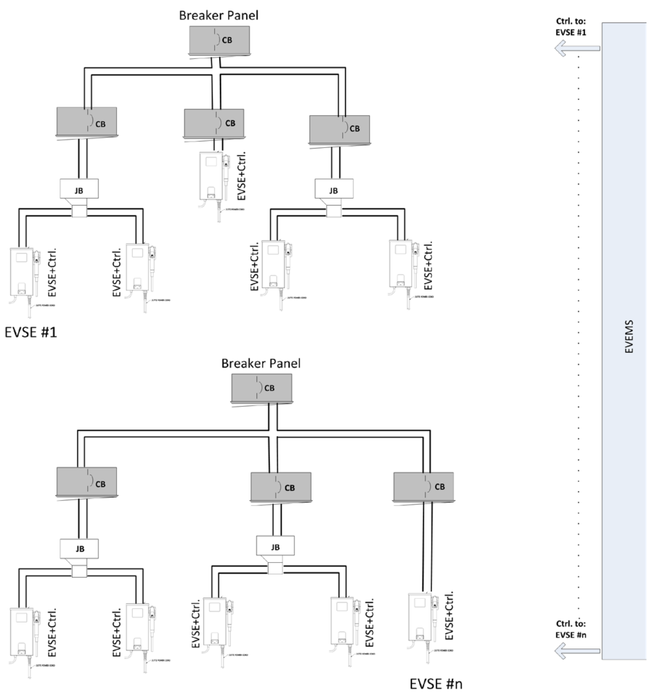
#### 3.2.4.1 Overview

The load management without monitoring approach is based on set power allocations to each EVSE for a specified time period. All power is fed from one branch circuit. In this approach, the power delivery is based on, and proportional to, the actual requirement of each EVSE. Each EVSE determines the power requirements of an EV (through the EVEMS) and apportions the power accordingly. Therefore, an EV with a lower charging requirement may receive a fixed percentage of the available capacity (i.e. 25%) for a period of time compared to an EV with greater charging needs, which may receive 50% to 100% of the available capacity.

This approach shares the electric circuit, panel or switchboard capacity among EVSE by dynamically allocating capacity among the EVSE. For example, one EVSE model sets allocations in increments of 25%. With this product, an EVEMS could determine that the first EV to connect is a plug-in hybrid with a relatively small battery, and provide a 100% power allocation since it is the only EV charging. A second EV might be a fully electric EV with a large battery, and therefore, upon connecting this EV to the system, the EVEMS might allocate 75% of the available power to the second EV and simultaneously reduce the plug-in hybrid allocation to 25%. The EVEMS ensures that the sum total of the EVSE current draw does not exceed the maximum capacity of each circuit. It does this not by measurement, but by communicating with each EVSE and controlling the power allocated to each EVSE to ensure it does not exceed the maximum circuit capacity. It is important to note that there is no support for uncontrolled loads, such as streetlights, using this approach.

Some EVEMS have the ability to determine the make of the EV connected through access to information linked to a user account. Radio-frequency identification (RFID) card, fob, or cell phone authorization is often required to initiate a charging session, which provides user identification and the ability to determine EV make. One vendor allows the user to enter vehicle state of charge, along with time required to be fully charged, and utilizes this information to optimize charging allocation. User accounts are often also used to manage payment. While those details are outside the scope of this report, it is useful to consider the method that an EVEMS uses to determine the kind of EV that is attempting to charge. This information may be used to optimize the circuit utilization, but is not a safety issue as long as the total allocation is monitored.

***Figure 4:*** *Load Management without Monitoring*




### 3.2.4.2 Advantages

The advantages of load management without monitoring include relative simplicity and the ability to operate with any EVSE capable of accepting charging rate change signals. This approach has the ability to reduce EVSE costs because measurement equipment is not required and service fees can be avoided. Further, relatively inexpensive EVSE can be used to charge a large fleet of vehicles in a building that has limited electrical capacity.

### 3.2.4.3 Disadvantages

The disadvantages of load management without monitoring schemes are increased cost compared to load sharing systems and inefficiency of power allocation compared to load management with monitoring schemes. For example, many vehicles reduce their power consumption as the battery approaches a full charge. While one vehicle may not be drawing the full percentage of power that it is allocated, another connected vehicle is not able to take advantage of the unused power allocation of the first vehicle.

### 3.2.4.4 Specific Safety Considerations

When using a load management without monitoring scheme, it is imperative that the EVSE go to a fail-safe mode when connection to the EVEMS is lost. Further, there may be safety issues with vehicles that do not respect the SAE J1772 pilot signal that dictates maximum current draw. This has not been an issue with current production vehicles, and any issue that would arise would be due to an EV not being compliant to the SAE J1772 standard. SAE J1772 requires that the EV respond to a change in the power allocation signal within 2 seconds. Such systems should only be used with EVs that are SAE J1772 compliant. Given this, the response time of the vehicle should be assessed, as the vehicle type is not part of the EVEMS installation, and therefore is not necessarily tested for safety.

## *3.2.5 Load Management with EVSE Monitoring*

### 3.2.5.1 Overview

The load management with EVSE monitoring scheme controls charging based on available capacity and the demand request of each EVSE. The EVEMS-EVSE system monitors the near real-time electrical consumption of an EVSE using CTs that are integrated into the EVSE, and allocates each EVSE's share of the available power based on actual usage (total power consumption). For example, a first generation Nissan Leaf can only draw 16 A. If this vehicle is connected to an EVSE, and a Tesla Model S, capable of drawing 32 A, is connected to a second EVSE, the EVEMS would allocate 16 A to the Leaf and (if sufficient electrical capacity is available) offer the Tesla the full 32 A.

One product uses an iterative approach whereby a new charging session is first offered 6 A. The EVEMS determines whether the EV is drawing the full 6 A and, if so, increases the power by 2 A. The monitoring cycle continues in this manner and power is increased until a maximum is reached. Charging is then maintained at this level. The EVEMS process operates on an IP gateway device located within close proximity to the EVSE.

Another vendor's approach first reduces the power level of an active charging session when a new charging session is added to the system. The maximum charging rate of the newly connected vehicle is then determined

*"The load management with EVSE monitoring scheme controls charging based on available capacity and the demand request of each EVSE."*

by increasing the power allocated to it at a high rate. The EVEMS then reallocates charging to all EVSE accordingly. The EVEMS is typically connected to an IP network and is located in the building associated with the parking.

A third approach available in the marketplace is to offer maximum power within capacity limits, and to subsequently monitor and reduce the power offered when a vehicle is underutilizing the allocated capacity. Unused power is then reallocated by the EVEMS to other vehicles. The EVEMS exists in the "cloud" and issues commands to reconfigure charging on a regular schedule, or as charging sessions are initiated or terminated.

Some systems utilize the "current offered" to vehicles to calculate circuit loading. Using this method, the EVEMS can control multiple EVSE connected to different branch circuits. More common is the utilization of electrical metering integral to each EVSE, to monitor actual consumption, and then adjust accordingly. The EVEMS are configured with appropriate capacity limits to effectively allocate power and protect branch circuits and/or panels from overload.

SAE J1772 specifies that EVSE constantly transmit a pulse width modulation (PWM) signal to a connected vehicle. PWM signals specify the amount of power the electric vehicle is permitted to draw. Historically, the signal was not adjustable and was fixed to match EVSE ratings. With controllable EVSE, the PWM signal can be altered to achieve appropriate charging. Adjusting charging power in accordance with the real-time demand of each charger is often referred to as "dynamic energy management". "Static energy management" generally describes a system that is limited to control based on the number of EVSE charging.

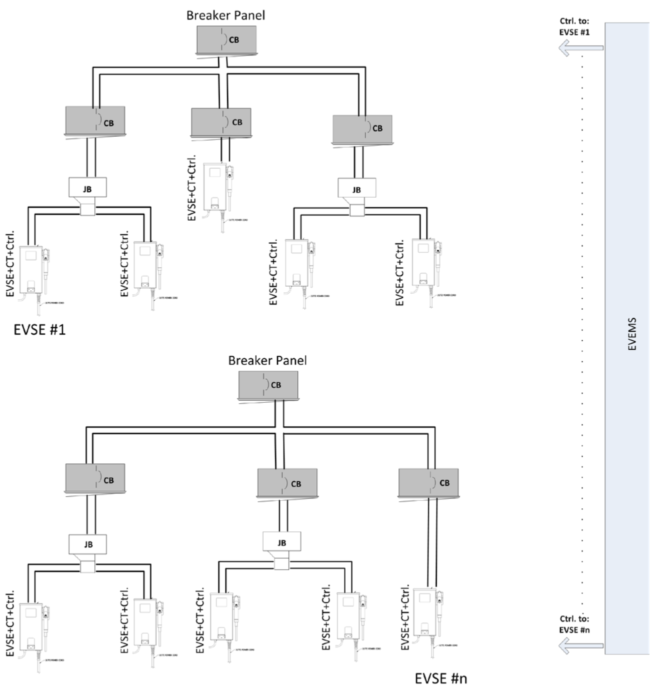
Each of these implementations use TCP/IP for communications reliability and security. Some systems also employ encryption. As such, the EVEMS are alerted of any communications errors. While a fail-safe response to such errors is not tested for in a standard, most systems employ a watchdog timer or similar approach and respond appropriately.

#### 3.2.5.2 Advantages

Load management with EVSE monitoring is a flexible and efficient energy management scheme. This scheme provides the ability to respond to the demands of each EVSE to maximize power delivery. It also can accommodate a higher number of EVSE compared to previously discussed approaches, and can do so without requiring electrical system upgrades.

The costs of these systems have reduced over time. They are expected to decrease further as the market matures, particularly with the influence of economies of scale. A number of manufacturers have introduced flexibility in purchasing arrangements to assist customers with initial supply and installation costs.

***Figure 5:*** *Load Management with EVSE Monitoring*




### 3.2.5.3 Disadvantages

The disadvantages of load management with EVSE monitoring approaches include

- Higher EVSE costs, proprietary systems;
- The prevalence of service fees; and
- Reduced charging performance compared to dedicated EVSE.

A site controller (either integral to the EVSE or standalone) with communications to a remote server is typically required.

Most EVEMS are exclusive proprietary systems with limited or no ability to operate with EVSE from other manufacturers. Open platforms such as Open Charge Point Protocol (OCPP) and Open Automated Demand Response (OpenADR) continue to advance, with OCPP 2.0 and OpenADR 2.0 providing substantial enhancements. Nonetheless, the availability of fully open platform EVEMS that can operate with EVSE from a variety of manufacturers is not anticipated in the short to medium-term.

Due to the relative infancy of EVEMS technologies, there are a limited number of available systems, and even fewer that are commercially viable and fully developed. This can be expected to change as the market matures, particularly as market value continues to rapidly increase. Further, the response times of some systems are not sufficient to maximize efficiency of the available capacity. The algorithms should improve as the systems advance to 2$^{nd}$ generation and beyond and more data becomes available to assist the product development process.

### 3.2.5.4 Specific Safety Considerations

Given that the load management with EVSE monitoring approach relies on communications with the EVEMS, it is imperative that the EVSE go to fail-safe mode when connection to the EVEMS is lost. The EVSE must also go to fail-safe mode when the EVSE detects that the vehicle is drawing more current than is permitted by the SAE J1772 pilot signal.

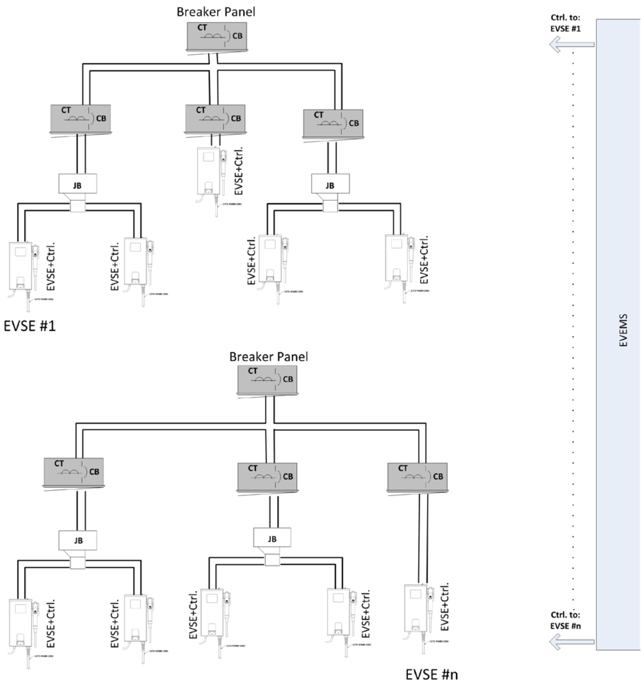
During commissioning, the EVEMS must be configured to identify each EVSE uniquely and to know which branch circuit it is assigned to. The complete configuration of the electrical system section related to the EVEMS must be known and configured accurately. Further, changes to the configuration must trigger a re-commissioning when new EVSE are installed, replaced, or relocated. Given the behaviour of the system, the monitoring speed must be fast enough to avoid a circuit overload that trips a breaker. This is typically a few seconds, not minutes. The calculated load should only be permitted to be zero if the response time of the system is fast enough. Life safety systems such as fire pumps should have a reserved calculated load that is added to the monitored actual load.

## *3.2.6 Load Management with External Monitoring*

### 3.2.6.1 Overview

The load management with external monitoring approach is very similar to the load management with EVSE monitoring approach, except that the CTs are installed at the branch circuit, feeder, and/or service entrance upstream from the EVSE rather than directly into the EVSE.

***Figure 6:*** *Load Management with External Monitoring*




### 3.2.6.2 Advantages

The main advantage of this scheme is cost, in that EVSE without integrated CTs can be deployed. Further, when CTs are installed at the main switchboard for a building, the power available for EV charging can be determined dynamically, as static peak load calculations rely on the difference between peak building demand and building electrical system capacity to determine the power available for EV charging. This approach therefore offers a much more efficient system, as is illustrated in Figures 7 and 8 below.

***Figure 7:*** *Power Available for Charging (Typical)*

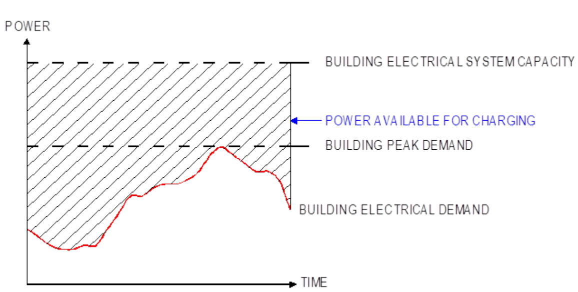
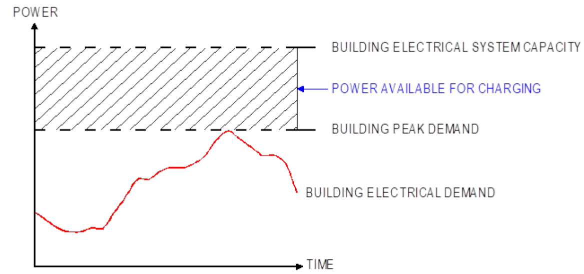



***Figure 8:*** *Power Available for Charging (with External Monitoring of Building Load)*




### 3.2.6.3 Disadvantages

The external monitoring approach has several disadvantages:

- first, this method requires increased setup and configuration effort to ensure the EVEMS monitors the breakers in near real-time.
- second, the EVSE must have fail-safe modes that turn the EVSE off when the EVEMS is unavailable.
- finally, the CT location requires upstream communication to the EVEMS as well as communication of a downstream load-limiting signal to the EVSE, thereby limiting branch circuit sharing.

### 3.2.6.4 Specific Safety Considerations

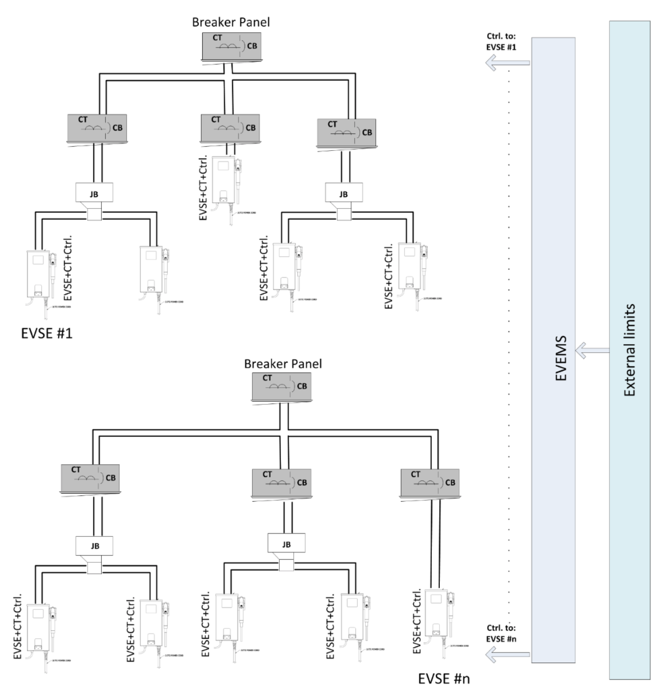
As discussed previously, it is imperative that the EVSE go to fail-safe mode when connection to the EVEMS is lost and the EVEMS must command EVSE to go to fail-safe mode when the CT is measuring more current than the EVSE are advertising.

## *3.2.7 Load Management with Monitoring at EVSE and External*

### 3.2.7.1 Overview

This scheme combines external monitoring with monitoring at the EVSE, with CTs installed both in the EVSE and at the panel feeder or the upstream end of the branch circuit feeding the EVSE (panel output). This approach allows the monitoring of uncontrolled loads, with the EVEMS reducing power to the EVSE based on the available power.

***Figure 9:*** *Load Management with EVSE Monitoring and External Monitoring*




#### 3.2.7.2 Advantages

This approach allows additional uncontrolled loads to be considered when the EVEMS is allocating power to vehicles. The system would support smaller installations that are extensions of the common or house panel. Where upstream loads are monitored at the building entrance supply, the calculated load for the EVs can be set to zero and charging would only occur when power is available below the pre-existing calculated load. This approach is extremely efficient in its use of available power.

#### 3.2.7.3 Disadvantages

This scheme involves greater setup and configuration effort to ensure that the EVEMS is monitoring the breakers in near real-time. The EVSE must have fail-safe modes that turn the EVSE off when the EVEMS is unavailable or if a communications error is detected by the EVSE. Further, if the EVEMS detects a communications error, it must set a condition that will be detected as a failure by the EVSE.

#### 3.2.7.4 Specific Safety Considerations

As discussed previously, the EVSE must go to fail-safe mode when connection to the EVEMS is lost and when the vehicle draws more current than the EVSE is advertising. The EVEMS must command the EVSE to reduce its charging rate and possibly go to fail-safe mode when more current is detected than the devices are offering.

The EVEMS must be configured during commissioning to identify each EVSE uniquely and to know which branch circuit it is assigned to. It must also know the complete configuration of the electrical system section related to the EVEMS and ensure it is configured accurately. Changes to the configuration must trigger a recommissioning when new EVSE are installed, replaced, or relocated.

Although the calculated load can be set to zero, there must be sufficient capacity that is unused by the EVEMS allocation to ensure that life safety systems such as fire pumps have reserved capacity that can switch on instantaneously (i.e. faster than the response time of the EVSE and EV).

## 4 Utility control

Some EVEMS have the ability to accept communications from the utility to restrict EV charging during peak demand periods. The purpose for such communications is to better assist utility companies in managing EVSE demand, particularly downstream in the utility distribution system where spare capacity is typically limited.

Utilities in California have championed efforts in this regard, motivated by electrical grids of limited capacity and earlier adoption of EVs. It is probable that utility control will become an issue of greater importance for Canadian utility companies as EV adoption increases. Major manufacturers for the Canadian market have held discussions with relevant utility companies about this issue.

Further evidence of a trend toward smart chargers and the ability for remote control is a recent announcement by the United Kingdom (UK) that all government-funded

*"Safety considerations are important for energy management systems given that software controls the loading on circuits and panels."*

EVSE installed from July 2019 must be capable of remote access and receiving, interpreting, and reacting to signals from a third party (most likely the utility).

## 5 General Safety Considerations

Safety considerations are important for energy management systems given that software controls the loading on circuits and panels. While overcurrent protection (i.e. circuit breakers and fuses) and bonding of electrical systems represent the fundamental safety mechanisms for protection against fire and shock hazards, EVEMS need to be designed in a manner that ensures against, as much as reasonably possible, reliance on such mechanisms. With increased loading on building electrical systems due to EVSE, the potential for issues escalates, particularly in older buildings.

With load switching and time allocation control schemes, safety concerns are inherent with regular switching of the input power of EVSE. Selection of EVSE not specifically designed to operate in this manner creates the potential for incorrect operation and premature failure.

Load management with external monitoring control schemes utilizes the available spare capacity of a building electrical system. It is important that the response times of these systems are adequate to ensure rapidly changing loads, particularly fire and life safety systems, are not impacted. Examples of common, rapidly changing loads include fire pumps, chillers, and elevators. A method for avoiding issues with rapidly changing loads is to configure service monitoring control schemes so there is no encroachment upon spare capacity for such loads. This represents the scenario for all other energy management control schemes. Technical Safety BC is considering introducing a requirement that all systems that encroach upon spare capacity for fire and life safety systems be hardwired to disconnect power to EVSE in the event of fire.

Fail-safe mechanisms are an appropriate requirement to protect against overload conditions in the event of a communications failure. Most products include some degree of fail-safe operation, although there are no standardized testing procedures to measure effectiveness and reliability and to ensure safety. A typical fail-safe operation in the event of a communication loss between EVSE and the EVEMS includes reducing EVSE power to a level below the rating of the circuits and/or panels while not allowing additional loads on the system, or disconnecting power to the EVSE.

The general approach pursued by Technical Safety BC is to designate general requirements and ensure an administrator is assigned to manage the system via an operating permit process. Refer to the "Conditions" section of Technical Safety BC's Information Bulletin (No: IB-EL 2018-01) for the Technical Safety BC variance process for *Electric Vehicle Energy Management Systems* [9].

The British Columbia Utilities Commission (BCUC) considers a person or organization providing EV charging services for compensation to be a public utility.[4] As such, safety matters pertaining to EVSE (and EVEMS, by extension) reside under BCUC jurisdiction and not electrical safety authorities. It is anticipated that this responsibility will eventually be transferred to electrical safety authorities (such as Technical Safety BC) through an appropriate regulatory mechanism. In general, the responsibility for product safety ultimately resides with manufacturers, electrical design with electrical designers (typically licensed professional engineers), and installation with electrical contractors.

Electrical safety authorities are introducing EVEMS commissioning requirements and manufacturers typically designate procedures. However, safety and efficiency would be improved through the development of standard commissioning procedures similar to those developed for fire and life safety systems.

## 6 Other Recommendations

### 6.1 Installation and configuration

To ensure EVEMS and associated EVSE are installed and configured correctly and safely, it is recommended that drawings and specifications, inclusive of load calculations, be required for all permit applications as per the Technical Safety BC variance requirements for *Electric Vehicle Energy Management Systems.* Further, it is recommended that only suitably qualified persons or manufacturer's representatives be permitted to configure EVEMS.

### 6.2 Logs

An electrical operating permit log is recommended for EVEMS and associated EVSE installations, as per the Technical Safety BC variance requirements for *Electric Vehicle Energy Management Systems* [9]. The log should contain system settings and load calculations prepared at the time of permit. Any alterations or modifications to EVEMS or EVSE, including changes to equipment operation should be recorded in the logbook. Only qualified persons or manufacturer's representatives should perform alterations.

### 6.3 Receptacles

Installation of receptacles for EVSE intended for operation with EVEMS, such as a CSA configuration 6-50R, may leave the system vulnerable to alterations by unqualified persons. Consideration of whether to restrict installations to hardwired connections should encompass all factors, including the responsibility and ability of EVEMS system administrators, strata organizations, and/or building managers to guard against unauthorized additions. Technical Safety BC and the City of Vancouver assign responsibility for the management of EVEMS to system administrators, and this approach is recommended.

### 6.4 Performance Requirements

EVEMS represent a compromise between electrical infrastructure costs and charging performance. The development of charging performance requirements is necessary to ensure a reasonable compromise is achieved. Charging performance requirements currently vary from region to region. Major factors include:

- daily driving distance;
- elevation variation;
- temperature; and
- vehicle types/efficiency.

While such assessment is outside the scope of this report, it is highlighted as an important component of ensuring EVEMS perform appropriately. The proposed reduced charging performance associated with EVEMS is not intended to be sufficient for all drivers at all times. Some drivers' needs will exceed the provisions and will require increased electrical infrastructure and/or the use of public or workplace charging to supplement home charging to support those needs.

Ideally, a consolidated assessment would be performed for all regions, as opposed to the current approach of individual jurisdictions. Minimum charging performance requirements would ideally accompany the legislation requiring EV charging, which in British Columbia has been an amendment of parking bylaws.

[4] BCUC report *An Inquiry into the Regulation of Electric Vehicle Charging Services,* Phase 1 (dated November 26, 2018)

There are many potential methods for defining charging performance, each with inherent advantages and disadvantages. To ensure clarity of requirements, avoid misinterpretations, and eliminate the necessity for designers to perform complex calculations, it is recommended that performance levels be provided in terms of the number of EVSE per circuit for various circuit ratings.

Charging performance assessments have been performed in British Columbia for the Cities of Richmond, Burnaby, Coquitlam, and Surrey that may provide assistance for similar assessments in other jurisdictions.

### 6.5 Circuit sharing potential

Increasing the number of EVSE connected to a circuit leverages sharing benefits and maximizes the utilization efficiency of electrical infrastructure, thereby reducing costs. The relationship between the number of EVSE on a circuit and charging performance is not proportional. Reduced electrical infrastructure costs would be achieved with the connection of ten to twelve EVSE on an 80 A circuit, as opposed to three or four EVSE on a 40 A circuit. The barrier to such a configuration is the certification of EVSE for specific upstream overcurrent protection, which for a Level 2 EVSE is typically 40 A. Including integral overcurrent protection for EVSE is an option, but typically increases costs to render the solution more expensive than a 40 A circuit configuration. Increasing beyond 80 A or 100 A also results in a more expensive solution as it requires a change in circuit breaker and panel type.

On the basis that EVEMS already protect circuits and panels from overload, it is reasonable to include protection of EVSE. Internal protections already inherent in EVSE and EV, which guard against overcurrent, also support a case for allowing connection of EVSE on circuits of higher ratings. For such a configuration to be permissible, an amendment to the *Canadian Electrical Code* and/or product certification designations would be necessary. Such a change may be appropriate given:

- the potential cost reductions;
- the ability to maximize use efficiency of electrical infrastructure and support additional EVSE on existing infrastructure; and
- the intrinsic positive influence towards mitigating barriers to EV adoption.

### 6.6 Security

EVEMS security is an issue of importance that should be addressed. Security concerns include the potential for unauthorized remote access (i.e. hackers) to change system configurations, control charging such as disconnecting all EVSE, and obtain personal details such as credit card information.

Major manufacturers have invested significant effort to ensure a high degree of cyber security for their systems. The implications of compromised systems affecting EVSEs charging or users' credit card information are of major concern. Security issues associated with building management systems (BMS), which became easy targets for hackers, and portals to corporate networks serve as examples to be avoided.

### 6.7 Failures

EVEMS failure is an issue that requires appropriate consideration given that the failure of an EVEMS or the associated communications could leave many vehicles without ready access to charging, potentially for extended periods. Solutions to this issue may include:

- redundancy requirements;
- EVSE that operate and provide adequate charging performance in the event of EVEMS failure; or
- the requirement for emergency maintenance access.

While few have positively embraced monthly service fees, ready access to maintenance in the event of failure is important.

### 6.8 Standard development

Standards have been developed for electric vehicles, providing guidance on electrical charging equipment to ensure safety in the use of such systems [1-8]. Standards for EVEMS would similarly provide a baseline for manufacturers as well as certification and testing laboratories, and should be sufficiently performance-based to avoid unnecessarily restricting product development and advancement and/or increasing costs. EVEMS standards requirements could potentially be incorporated as an additional section in existing standards or as separate, standalone standards.

## Conclusion

EVEMS represent an opportunity to maximize utilization efficiency of electrical infrastructure and to reduce costs. Energy management represents a compromise between cost and charging performance. It provides an opportunity to avoid costly upgrades in existing facilities and oversizing electrical infrastructure for new construction.

While the technology is in relative infancy, there are viable commercial products currently available and many installations already in North America. Economies of scale can be expected to assist technology advancement and reduce costs. Furthermore, the trend toward greater connectivity through the IoT and smart building technologies supports the position that EVEMS have a vital role to play in the future of EV charging, and will encourage EV adoption through the mitigation of cost barriers.

With software controlling electrical loading on circuits and panels, safety is an important issue. Appropriate fail-safe mechanisms, configuration, testing and commissioning, and management procedures are required to ensure systems function correctly, and that in the event of error or failure, impacts are minimized and do not present a safety hazard. It is recommended that the configuration and management of EVEMS be performed by suitably qualified persons, and that appropriate records be maintained to document amendments to the systems.

There are a variety of energy management configurations and control schemes, each with advantages and disadvantages, and specific installations in which they are most suitable. The three variations of load management with monitoring are the schemes that achieve greatest utilization efficiency of electrical infrastructure, and following logical conclusions, provide the most probable long-term solution for EV charging.

A standard for EVEMS would provide guidance for product manufacturers, research teams, testing and certification laboratories, regulatory and inspections authorities, electrical engineers, and electrical contractors. Further, it would remove existing barriers to technology use and would assist in efforts to accommodate and encourage EV adoption.

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## CSA Group Research

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