Electric Vehicle Dynamic Charging Performance Characteristics during Bulk Power System Disturbances

Synopsis

The purpose of this document is to highlight the need for collaboration between electric utilities and the electric vehicle (EV)/electric vehicle supply equipment (EVSE) manufacturing industry to develop strategies that will help ensure bulk power system (BPS) reliability, resilience, and security.[1] This document focuses on an area that is relatively unexplored: EV charging behavior during infrequent grid disturbances that originate from the BPS. These events last no more than a few seconds but may have catastrophic consequences for grid reliability if left unchecked (i.e., cascading blackouts and widespread power interruptions). This document outlines the need for early engagement and information exchange between the electric utilities and the EV/EVSE manufacturing industry to facilitate anticipation and timely resolution of potential grid reliability issues. Toward this end, this document describes the BPS-related reliability concerns that electric utilities are studying in anticipation of the expected significant increase in EV charging loads. This document then outlines the electric utility's current recommendations to mitigate these concerns based on preliminary observations, including changing EV charger and EVSE operation during these infrequent, short-duration events. This document concludes by outlining a solution to meet the need for on-going information sharing between the two communities. This includes the need for future studies to refine these recommendations to become accepted industry practices and standards. This coordination will foster mutual understanding of the issues that must be addressed on both sides of the meter to ensure grid reliability, resilience, and security at the least cost to society as electrification of the transportation fleet grows.

California Mobility Center Electric Vehicle Grid Reliability Working Group

In June 2022, the California Mobility Center (CMC)[2] formed an EV Grid Reliability Working Group (Working Group), an initiative of diverse EV and grid reliability stakeholders with an interest in advancing understanding and collaboration regarding EV charging demand and grid reliability issues.

The following are the goals of the Working Group:

- Develop a common baseline understanding of the relationship between both distribution and transmission grid reliability and EV charging

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[1] For the purpose of this discussion, electric utilities refers to the segment of the electricity industry responsible for the reliability of the high-voltage BPS and EV/EVSE manufacturers refers to the segments of the automotive industry involved in either manufacturing EVs or EV supply equipment.

[2] The CMC is a not-for-profit public-private collaborative whose goal is to accelerate innovation and commercialization of new products, services, and technology in the clean mobility space. The CMC provides members and other stakeholders with opportunities to work together with thought leaders engaged on issues that are critical to advancing EV adoption and deployment, supporting state and national energy, and environmental goals.

- Enable information and data exchange as well as collaborative discussions to support the development of advanced models and study techniques essential to performing reliability studies in the long-term grid planning horizon
- Develop industry guidance to proactively support the mitigation of possible adverse reliability impacts on distribution system and BPS with growing EV charging loads
- Further the advancement of new EV technologies, tools, and capabilities supporting electric distribution and BPS reliability and resilience
- Disseminate and share insights and guidance with stakeholders, including EV manufacturers, charging station manufacturers, utilities, regulatory organizations, policymakers, and others

The North American Electric Reliability Corporation (NERC)[3] and the Western Electricity Coordinating Council (WECC)[4] executed a memorandum of understanding with the CMC in support of this Working Group's efforts, with a focus on coordinated efforts to ensure BPS reliability, resilience, and security with growing levels of EV charging loads across California and North America. Experts from Lawrence Berkeley National Laboratory, the Electric Power Research Institute, and numerous other organizations are also providing support.

The Working Group has conducted a series of monthly calls to discuss many different aspects of EV charging impacts to grid reliability. Topics have included EV charger interconnection standards; EV charging impacts on North American and California electricity demand forecasts, load shapes, and load bus allocations; framing distribution and BPS reliability for EV charging; evolving utility and equipment standards; managed charging programs; and opportunities for EV charging to enhance grid reliability.

Introduction

The adoption of EVs is projected to grow rapidly over the coming decades (see Figure 1). To support this growth, the U.S. Energy Information Administration forecasts that electricity consumption by the transportation sector will increase by more than a factor of 12 between 2021 and 2050 (from 12 billion kWh in 2021 to more than 145 billion kWh in 2050).[5] Considering all forms of electrification across North America, Wood Mackenzie projects that electricity consumption in 2050—by transportation and building electrification after subtracting projected increases in on-site generation (e.g., rooftop solar PV)—will represent a 66% increase over total electricity consumption in 2022.[6]

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[3] NERC is designated as the Electric Reliability Organization (ERO) by the Federal Energy Regulatory Commission as (FERC) and is responsible for assuring the effective and efficient reduction of risks to the reliability and security of the BPS in North America: https://www.nerc.com/

[4] WECC is the FERC-approved Regional Entity formed to assure BPS reliability in the Western Interconnection: https://www.wecc.org/

[5] https://www.eia.gov/outlooks/aeo/narrative/electricity/sub-topic-01.php

[6] Personal communication. Fahimeh Kazempour, Wood Mackenzie. February 21, 2023. Note: nearly 80% of the net increase is due to transportation electrification; building electrification accounts for less than 20% of the net increase.

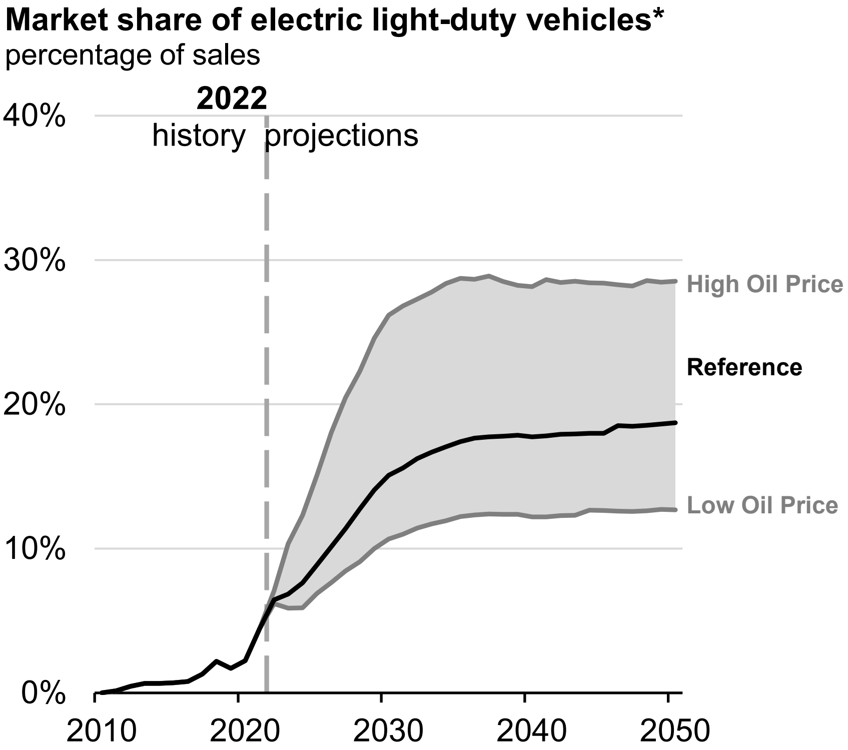

Figure 1: Market Share of Electric Light-Duty Vehicles [Source: U.S. Energy Information Administration][7]

The transportation sector will increasingly depend on the safe, reliable, affordable, and secure delivery of electric energy to EVs. The dramatic increase in demand required to support the growth of EVs will challenge the electric power system in many ways. The rapid growth in demand from EV charging, which consists of loads that are connected to the grid through power conversion inverters, is unprecedented and is taking place at the same time electricity system operators and planners are also focused on integrating rapidly growing levels of inverter-based generation resources, extreme weather impacts, and increasingly malicious security threats.[8]

EV charging affects the electric power system across the entire spectrum of grid operational timeframes (see Figure 2).

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[7] Annual Energy Outlook 2023 (AEO2023)

[8] See NERC Long Term Reliability Assessment, December 2022; NERC 2022 State of Reliability Report, July 2022

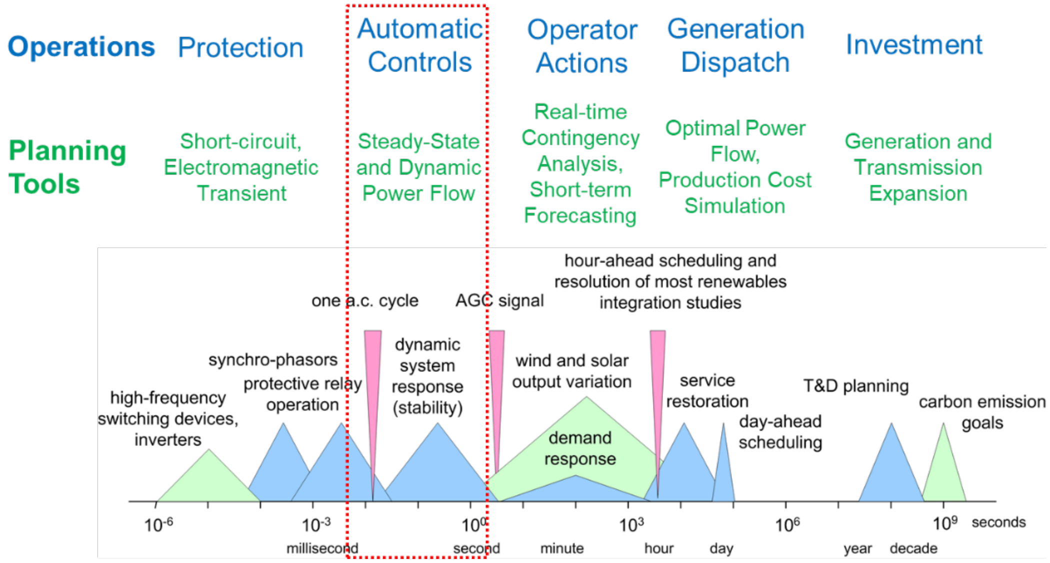

Figure 2: Time Frames of Grid Reliability
[Source: Adapted from NASEM][9]

The Working Group expects these effects on the electric power system will only intensify as the penetration of EVs on the grid increases. These impacts must be managed in order to maximize the speed of adoption. Examples include, but are not limited to, the following:

- Demands on distribution providers to process EV charging load interconnection requests may increase faster than can be managed by these providers and lead to delays in new interconnections.
- Significant increase in distribution system hosting capacity and loading effects may cause operational problems in distribution systems requiring expensive, last-minute upgrades in order to accommodate EV charging demands.
- Large-scale changes to demand profiles due to unmanaged EV charging behavior, time-of-use rates, and distributed renewable energy resources (DER) may lead to resource adequacy shortfalls and create needs for short-term, emergency rationing, such as planned, rolling blackouts.
- Faster load growth than is anticipated by current demand forecasts may have unexpected negative consequences for capacity and energy resource plans.
- The need for flexible ramping resources and reserves carried by BPS balancing authorities (BA) and transmission operators (TOP) may grow faster than that which has been anticipated in current long-term planning and operational planning studies.

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[9] National Academies of Sciences, Engineering, and Medicine 2020. Models to Inform Planning for the Future of Electric Power in the United States: Proceedings of a Workshop. Washington, DC: The National Academies Press. https://doi.org/10.17226/25880

- Increasing variability and uncertainty in distribution and transmission system demand patterns may lead to unexpected operational challenges and the need for emergency demand rationing (i.e., rolling blackouts).
- Negative effects on distribution system and transmission system protection system operations may lead to unplanned power interruptions.
- Effects of grid dynamics, controls, and system stability due to the power electronic behavior of the EV charging loads may create new risks of widespread, cascading blackouts.

This document focuses on the dynamic system with respect to BPS reliability. The time frames involved range from milliseconds (one thousandth of a second) to seconds. In this time frame, automatic and autonomous (i.e., independent) controls and protections must operate quickly in a pre-coordinated manner to ensure the safety and reliability of the power system. Dynamic stability simulation tools must be relied upon to study and pre-plan the automatic actions that grid equipment must take to ensure that the BPS will remain stable and reliable during large grid disturbances. To consider all possible scenarios, hundreds or even thousands of distinct "what if" simulations are necessary.

Background

NERC has been designated by the Federal Energy Regulatory commission as the Electric Reliability Organization (ERO) within the United States to establish and enforce reliability standards for the U.S. portion of the BPS, pursuant to Section 215 of the Federal Power Act (FPA)[10]. NERC, WECC and five additional regional reliability organizations also conduct assessments of the reliability of the BPS and work closely with transmission owners and operators to develop and share guidelines to ensure BPS reliability.

Transmission planning studies are conducted on a continuous basis to ensure that the BPS can be operated reliably under all anticipated conditions. A special emphasis of these studies is to plan the actions required to ensure stable operation following unexpected events, such as the unplanned, sudden loss of a large generator or transmission line due to equipment failure or severe weather.[11]

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[10] As of June 18, 2007, FERC granted NERC the legal authority to enforce Reliability Standards with all U.S. users, owners, and operators of the BPS and made compliance with those standards mandatory and enforceable. Section 215 also requires that the organization certified by FERC as the ERO seek recognition with relevant authorities in Canada and Mexico. In 2005, the U.S. Department of Energy (DOE) and Canadian federal and provincial governments agreed to bilateral principles for a consistent, continent-wide reliability regulatory framework under a non-governmental institution (the ERO) designed to function on an international basis. To date, NERC has memoranda of understandings (MOUs) with eight Canadian provinces2 and the Canada Energy Regulator in furtherance of this framework. NERC works with the Mexican regulator, Comísion Reguladora de Energía (CRE), and the Mexican system and market operator, CENACE, under a MOU signed in 2017 to ensure consistency with the framework in Canada and the United States

[11] In these instances, loss refers to the actions of automatic controls that disconnect a generator or transmission line from the surrounding electricity grid either to protect other equipment from damage or to isolate a problem before it can spread.

In 2015, the planning standards that must be followed in conducting these studies were revised to require the use of dynamic load models, called composite load models.[12] The revisions were based on findings from the investigation of the causes of the 1996 U.S. West Coast blackouts. The investigation concluded that the mathematical representation of the loads served by the power system that had been relied on in the planning studies leading up to the blackout were grossly inadequate. The distinguishing feature of the composite load model is an explicit representation of the dynamic behavior of the different constituents of load at each load-serving node within a utility's transmission planning models. The most important of these constituents are motor-driven and power electronics-based loads, such as EV chargers.

The U.S. Department of Energy (DOE), through its national laboratories, has long provided technical support to NERC and transmission planners on dynamic load modeling. The collaboration began in 2010 when DOE was asked by NERC to lead a national initiative on the study of fault-induced delayed voltage recovery (FIDVR) that is caused by residential air conditioners that stall simultaneously when transmission systems experience an otherwise routine fault. At the time, there was concern that, left unchecked, a FIDVR event might lead to a BPS cascading voltage collapse and cause widespread blackouts.

DOE and NERC held several workshops where technical findings from DOE-funded studies were presented and joint discussions were held that involved leading engineers from both the power systems and the air conditioning manufacturing communities. These groups shared testing and performance information on air conditioners so that more accurate transmission planning studies could be conducted.[13] A key outcome of these workshops and related industry studies was improvements to the representation of air conditioners in the composite load model. In one instance, a Southern California utility spent $50 million to reinforce a substation in part of their service territory where numerous FIDVR events had been recorded specifically to mitigate the threat of blackouts.

A key the objective of NERC's present engagement with the CMC Working Group is to foster a comparable information-sharing based collaboration between the electric utility and the EV/EVSE manufacturing industries. This collaboration has already begun through the sharing of past studies.

One notable study involved use of simulation tools to model the impacts of EV charging on the aforementioned problem of FIDVR. The study found that some EV charger models responded in a manner that is grid friendly, meaning that their behavior supported rapid restoration to a stable operating condition.[14] At the same time, the study also found instances when other EV charger models responded in a manner that is grid unfriendly, meaning that their behavior was

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[12] https://www.nerc.com/_layouts/15/PrintStandard.aspx?standardnumber=TPL-001-4&title=Transmission%20System%20Planning%20Performance%20Requirements&jurisdiction=United%20States

[13] https://certs.lbl.gov/initiatives/fidvr/

[14] Tuffner, F., J. Undrill, D. Scoffield, J. Eto, D. Kosterev, and R. Quint. Distribution-Level Impacts of Plug-in Electric Vehicle Charging on the Transmission System during Fault Conditions. Pacific Northwest National Laboratory, Richland, WA. PNNL report 031558. October 2021: https://eta-publications.lbl.gov/publications/distribution-level-impacts-plug

detrimental to the restoration of stable operating conditions. The study recommended testing and validation of the actual performance of newer generations of EV chargers and EVSE to improve the basis for future planning studies.

Grid-Friendly EV Charging Dynamic Behavior

"Grid-friendly" EV charging performance characteristics (either on-board or through EVSE) as they relate to BPS reliability are based on foundational power system stability concepts: transient stability, frequency stability, voltage stability, asymptotic stability, ride-through performance, and the essential BPS reliability services required to manage them.[15,16] Electric industry experts and national laboratories have drawn from this body of knowledge and experience to develop a baseline set of recommendations for grid-friendly EV charging.[17,18]

This section reviews these recommendations. The review describes how specific aspects of EV charging behaviors may either contribute to grid reliability (i.e., they are grid friendly) or are detrimental to grid reliability (i.e., they are grid unfriendly). The review emphasizes the critical need for additional testing and validation of the actual and expected future behavior of EVs and EVSEs.

Steady-State Consumption Control

Historical electric end-use loads, such as resistive heating, lighting, and cooking were considered grid friendly because their electrical characteristic is constant impedance. As voltage dropped slightly, the device power draw would also reduce and hence support stable steady-state operation of the grid. Many, if not most, of today's electronically-coupled loads do not exhibit this constant impedance characteristic; rather, their power electronic controls seek to maintain either a constant current level or a constant power level regardless of system voltage or frequency (within a normal operating band). When they seek to maintain a constant power level, these loads are not grid friendly from a grid dynamics and stability perspective. A constant power load exacerbates system instability because, during events on the system when voltage reduces, the load draws more current in order to maintain constant power. In contrast, constant current loads maintain a fixed level of a current consumption, independent of voltage, which is "grid friendly." That is, this behavior allows power consumption to drop slightly when system voltages decline.

> **Recommendation:** EV chargers and EVSEs should employ a steady-state control strategy that use constant current control rather than constant power level control during normal operations.

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[15] Kundur, P., Paserba, J., Ajjarapu, V., Andersson, G., Bose, A., Canizares, C., Hatziargyriou, N., Hill, D., Stankovic, A., & Taylor, C. (2004). Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions. *IEEE Trans Power Syst, 19*(3), 1387–1401.

[16] https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF%20Framework%20Report%20-%20Final.pdf

[17] Quint, R., D. Kosterev, J. Undrill, J. Eto, R. Bravo, J. Yen. Power Quality Requirements for Electric Vehicle Chargers: Bulk Power System Perspective. 2016 IEEE Power and Energy Society General Meeting. 17-21, 2016. Boston, MA. DOI: 10.1109/PESGM.2016.7741443

[18] https://eta-publications.lbl.gov/publications/distribution-level-impacts-plug

Following this recommendation enables variations in power consumption in direct proportion to changes in voltage. Therefore, when grid voltages are depressed during unexpected emergencies, EVs and EVSEs support the grid by reducing their power consumption, improving overall grid voltage stability.

Power Factor

Many equipment standards often focus on power quality issues, and power factor typically will fall into this category (in addition to the harmonic distortion requirements). Specific equipment standards, such as the Society of Automotive Engineers (SAE) requirements, may dictate certain power factor (and harmonics) requirements for EVs and EVSEs.

> **Recommendation:** EV chargers and EVSEs should operate with a power factor (at fundamental frequency) of 0.985 or higher (leading or lagging). Power factor should be maintained for ac supply voltages from 80% to 110% of nominal voltage.

A reasonably tight control of power factor ensures that distribution system voltages can be managed appropriately and also ensures that the distribution system will not experience significant draws of reactive power unexpectedly, which could affect BPS voltage stability across the transmission-distribution interface where load tap changes automatically attempt to regulate voltage.

Frequency Response (Active Power-Frequency Control)

EVs and EVSEs can support grid reliability by actively contributing to system frequency response. System frequency response involves autonomous minute changes in active power (active current) to control system frequency. The ability of end-use loads (and generators) to support grid frequency is a core tenet of overall grid reliability. All newly interconnecting generating units on the BPS are required to have active power-frequency controls.[19]

Active power consumption should be proportional and in opposition to changes in frequency measured at the EV charger or EVSE. This type of response is conducive to overall frequency stability and frequency response of an interconnected synchronous power system. Proportional reduction in EV charging loads and EVSE power draw supports control of grid frequency by reducing power consumption during low frequency conditions.

> **Recommendation:** EV chargers and EVSEs should have a programmable current consumption droop characteristic with a programmable range and a default value of 5%.

A 5% frequency droop (e.g., 3 Hz on a 60 Hz system) means that current consumption would go from 100% to 0% for a frequency drop from 60 Hz to 57 Hz.

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[19] Refer to FERC Order No. 842 for more details.

It is also critical to have load response coordinated with underfrequency load shedding[20] (UFLS) actions. The first step of UFLS is typically set around 59.3 Hz (0.7 Hz change from nominal).

> **Recommendation:** EV chargers and EVSEs should be programmed with the capability to rapidly reduce current consumption for severe frequency excursions before UFLS levels are reached.

Following this recommendation would enable these loads to support grid frequency response and return to service seamlessly with very minimal impact to end-user experience. Response times to changes in measured frequency should occur within 100–200 milliseconds. Frequency should be measured over a time window (e.g., multiple electrical cycles); frequency should not be measured instantaneously for these types of applications.[21]

For example, Figure 3 shows a simplified[22] frequency response characteristic where EV charging power (or EVSE power draw) is reduced from 100% full consumption down to 99.5% for a frequency excursion down to about 59.7 Hz (typically observed during large generator tripping disturbances on the grid). Below 59.7 Hz, the load should rapidly reduce current consumption to help stabilize frequency automatically. The load should then return to the droop characteristic when frequency recovers above some threshold (e.g., 59.9 Hz). During normal grid disturbances, this recovery typically takes place in less than a minute. System frequency generally does not remain below these cutout levels during normal operation for very long; this is indicative of a severe generation-load imbalance and impending frequency collapse. EV chargers and EVSEs that support frequency control in this manner are grid friendly.

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[20] UFLS is a safety net scheme deployed across interconnected power systems that disconnects dedicated distribution loads and circuits in an effort to maintain frequency stability across the interconnected power system (i.e., trip some loads in an effort to save the system from widespread blackout). These safety nets are rarely deployed and generally used only in emergency conditions.

[21] This issue has been observed in solar PV inverter controls and protection systems and has caused erroneous tripping at these facilities.

[22] This figure is simplified in that typically a non-step deadband around nominal 60 Hz is used to avoid chatter during normal operations. A deadband of +/- 17 mHz is often used for power electronic resources.

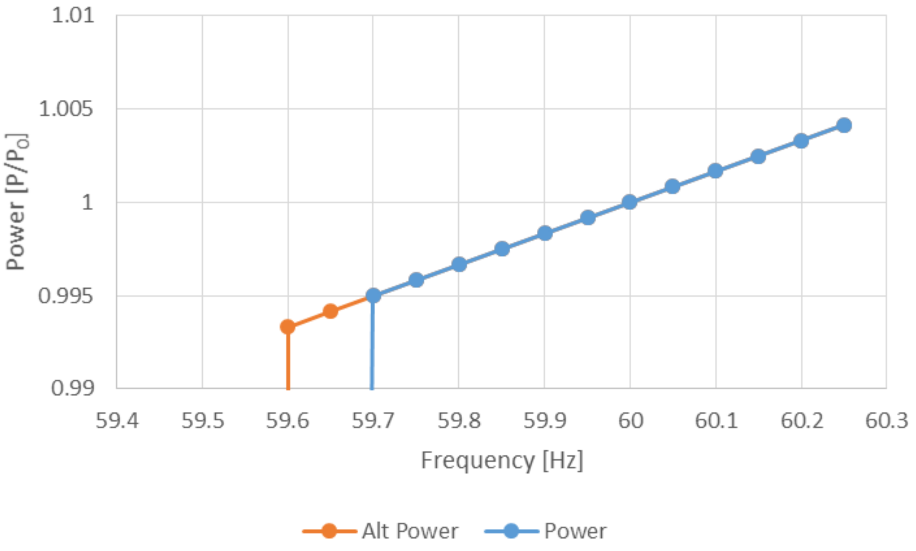

Figure 3: Simplified Example of EV Charger Load Frequency Droop Characteristic [Source: Quint, et al.][23]

Ride-Through Performance: Remaining Connected during Grid Disturbances

It is critical for elements connected to the grid to have reasonable and grid-friendly ride-through responses and capabilities. Historically, the physical characteristics of end-use loads along with the diversity of different load types provided a strong understanding for grid reliability engineers to ensure reasonable performance of the BPS. With increasing levels of power electronics interfaced/decoupled loads, it is important to ensure that equipment standards support grid-friendly behavior of these elements.

Disconnection and connection settings are key to ensuring stable grid frequency and voltage support during loss of generation events and grid faults. The behavior of large loads (or large aggregate levels of loads) must be coordinated with distribution and transmission level protections and safety net schemes put in place. Some degree of randomization (or ranges of adjustability) can help with load performance diversity; however, reasonable bounds must be established based on grid needs.

Ride-through performance can be categorized loosely into the following modes of operation:

- **Continuous Operation:** Steady-state operations or minor grid disturbances (e.g., distant faults and generator trips, line switching) where EV chargers and EVSEs should remain connected to the grid and consuming constant current

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[23] Quint, R., D. Kosterev, J. Undrill, J. Eto, R. Bravo, J. Yen. Power Quality Requirements for Electric Vehicle Chargers: Bulk Power System Perspective. 2016 IEEE Power and Energy Society General Meeting. 17-21, 2016. Boston, MA. DOI: 10.1109/PESGM.2016.7741443

- **Ride-Through Operation during Large Grid Disturbances:** Response to larger grid disturbances (e.g., close-in or three-phase faults, delayed clearing protection system operations, large frequency excursions, other natural disasters) where EV chargers and EVSEs should use their power electronics to dynamically control current consumption based on measured terminal conditions in a way that supports grid reliability
- **Severe and Unexpected Grid Conditions:** Response to extreme grid events (e.g., system separation, cascading outages, blackouts) where EV chargers and EVSEs should disconnect from the grid and return using "cold load pickup" protocols

Each EV charger and EVSE should be programmed to respond autonomously to their measured terminal conditions and support grid reliability. Grid-friendly performance characteristics in this time frame should not require any advanced communications between devices or with the grid operator(s); rather, converter protection and controls should respond automatically to modify EV charging behavior and operation. Details regarding the exact manner in which EV chargers and EVSEs should respond is an important area to address in future modeling and validation efforts.

Ride-Through Performance: Dynamic Response Times

During ride-through operation, it is important that EV chargers and EVSEs dynamically respond to measured terminal conditions with an appropriate charging performance characteristic. This requires rapid measurement through the power electronics and sufficiently fast response times to manage current consumption while ensuring equipment integrity. For example, EV chargers and EVSEs should dynamically control current consumption, with any ceasing (or ramping down) and resumption (or ramping up)[24] of current in a manner that supports grid reliability. Figure 4 illustrates an example of a grid-friendly response as compared to a grid-unfriendly response. The details of the performance characteristic are described below; specifically note the response of current (and power) consumption immediately at the time of the fault. The grid-friendly EV charging load nearly-instantaneously reduces current consumption for a short amount of time; the grid-unfriendly EV charging load does not respond to the event (i.e., the fault) until after it is already cleared and voltage has recovered. In essence, the response of the EV charging load in the latter example does not occur until after the event is over, which does not support grid reliability, and can potentially be detrimental to the overall grid performance, reducing reliability. Specific response characteristics are discussed below. The goal here is to illustrate concepts and suggest general response characteristics and times; however, specific requirements should be specified with more technical detail in the validation studies and equipment standards outlined under Next Steps in this document.[25]

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[24] The ability of end-use loads to quickly return to pre-disturbance levels after detection of acceptable system conditions can help avoid grid overvoltage conditions. Significant end-use load disconnection or tripping can result in severe distribution and transmission system overvoltage conditions that adversely affect grid reliability.

[25] Such as SAE J2894

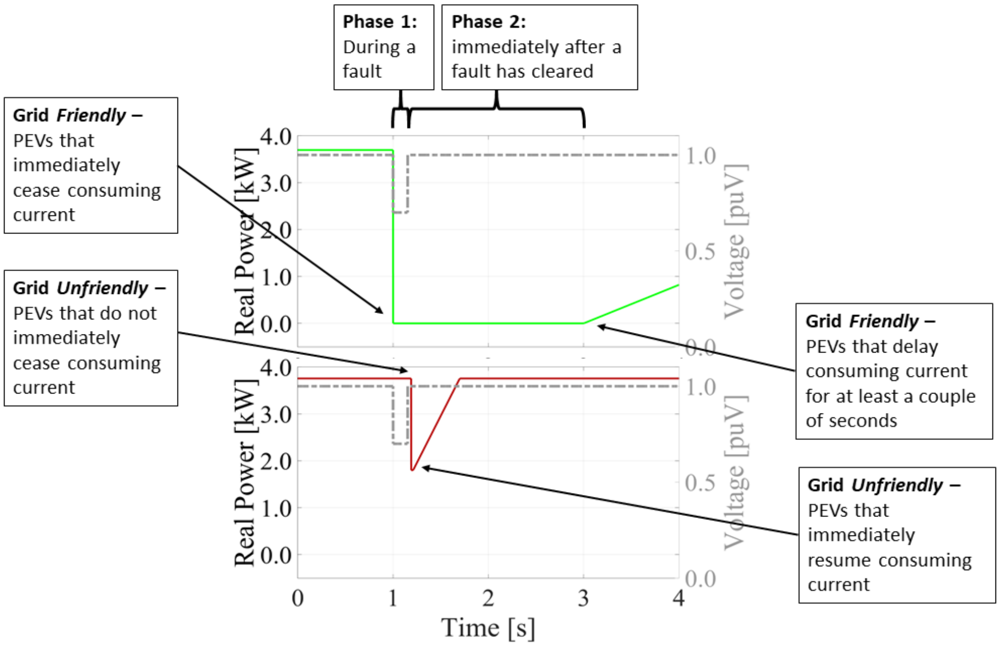

Figure 4: Grid Friendly and Unfriendly Charging Behaviors [Source: PNNL][26]

Ride-Through Performance: Voltage Characteristics

The dynamic response of active current consumption during ride-through operation should be proportional to measured terminal voltage.

> **Recommendation:** Response time to changes in voltage should be less than 20 milliseconds (or approximately one cycle).

Any slower response time would be too slow to support BPS reliability. Programming these response times is reasonable, as many other power electronic assets connected to the grid (e.g., wind, solar photovoltaic, battery energy storage systems, etc.) meet this performance requirement today.

When a fault causes terminal voltage to drop significantly, the EV charging controls may cause current consumption to change rapidly; therefore, it is common for current-limiting controls to help protect the EV and EVSE equipment before the need to trip. EV chargers and EVSEs should remain connected and consuming constant-current for terminal voltage sags as low as 80% (or maybe even deeper, in constant-current control mode).

For deep voltage depressions caused by local or severe fault events, it may be advantageous for EV chargers and EVSEs to momentarily cease or ramp down current consumption using the power electronic controls. Fast, controlled ramping may occur for deep voltage sags below, say, 80%.

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[26] https://eta-publications.lbl.gov/publications/distribution-level-impacts-plug

Some randomizations to the reduction level can help with load response diversity (e.g., ramping down between 70–80%) and ensure smooth controlled response rather than large discrete changes in aggregate load level. Active current consumption should drop rapidly below these levels to support power system dynamic performance during and immediately following faults. EV charging loads should resume current consumption when voltage recovers to within the normal operating range (e.g., above 90–95% of nominal). The rate of active current consumption should be a programmable setting for EV charging with a reasonable default time of around 250 milliseconds back to predisturbance charging levels. Very fast recovery could cause stability issues while overly elongated recovery could result in post-fault overvoltage conditions.

Next Steps: Enhance Mutual Understanding of the Grid Reliability Impacts of EVs and EVSEs

Electric utilities are proactively initiating planning studies in anticipation of the expected massive increase in electricity loads required to support EV charging. Drawing on past experiences with motor-driven loads and recent experiences with inverter-based generation, initial perspectives have been developed on the ways in which EV chargers and EVSEs can operate in a grid-friendly manner that would support BPS reliability, resilience, and security yet have no appreciable impact on charging performance (e.g., charging times).

Preliminary testing has confirmed that some EV chargers already appear to behave in a manner that is grid friendly during the very infrequent, short-lived times (lasting no more than seconds) when the grid is under stress. This is encouraging because it suggests that only modest changes might be required to make all EV charging and EVSE technologies operate in a grid-friendly manner.

The expected, continued rapid change in EV charging and EVSE technologies underscores the need for on-going two-way communication and standardized information sharing between the EV and EVSE manufacturer industry and the electric utilities. It is incumbent on the electric power industry to communicate its reliability concerns and the information it needs to inform the steps it must take to address them with its counterparts in the EV and EVSE industries. It is equally incumbent on the EV and EVSE industry to communicate its commercial concerns and how they will affect the future evolution of EV and EVSE technologies that will rely on the grid. The goal is to foster mutual understanding of the issues that must be addressed on both sides of the meter to ensure grid reliability at least cost to society as electrification of the transportation fleet grows. These are important considerations as the grid of the future emerges. BPS reliability and resilience will be vital to support the EV and EVSE requirements that society requires, and EV chargers can play a significant role in this vital outcome.

The current focus of electric utilities is on improving understanding of how EVs and EVSE's behave during both normal operation and grid disturbances. It is a given that each EV and EVSE OEM implements their controls in accordance with internal design practices. Despite these differences, electric utility experience has shown that representative models can be developed of the aggregate behavior of EV charging, and this is assuming adequate equipment standards and grid codes are in place that codify the bounds of and any acceptable deviation from acceptable performance (as described above).

NERC and its industry stakeholders are actively developing and testing a new aggregate EV charging load model that can be used in BPS grid reliability studies.[27] NERC will soon be releasing its findings on the usability of the aggregate EV charging load model as well as the possible impacts to BPS grid reliability that will occur with rapidly growing EV charging loads across North America. Findings from these studies are expected to enhance and refine the recommended performance characteristics listed above.

EV and EVSE OEMs are strongly encouraged to collaborate with NERC and the national laboratories through the exchange of EV charger performance data as an input to modeling and validation initiatives that will take place in the coming years. Subject to verification of projected potential grid impacts, it will be imperative that these groups collaborate and reach consensus regarding what is considered grid friendly and how that can be implemented effectively in current and future technologies. The nature of the power electronic controls used in EV charging loads (and many other generation and end-use load technologies) provides great flexibility and an opportunity for all elements reliant on the grid to support overall system reliability.

The recommendations in this document should be considered, validated, and incorporated into ongoing grid, EV and EVSE standard efforts where appropriate. Taking into consideration study outcomes, future industry efforts should enhance EV charging load testing and certification programs to operationalize this guidance. Stakeholders are also encouraged to engage with the Electric Power Research Institute, SAE,[28] and other organizations to further advance these recommendations. Given that the guidance in this document is based on well-established electric system engineering and knowledge gained over decades by system operators, planners, and research organizations, appropriate next steps include demonstrations with EV and EVSE OEMs to validate models to support system studies. Pending these developments and study results, EV and EVSE OEMs are encouraged to take these recommendations into consideration as they undertake enhancements in the design and operation of their EV charging equipment, software, and related systems.

Properly modeling the aggregate EV charger performance is critical for ensuring that system planning and operations studies accurately represent the grid and its interconnected elements. Grid planners and operations engineers rely on this information to establish infrastructure plans and set operating limits. Therefore, collaboration across sectors will be increasingly important as EV charging loads continue to grow and increase their impact on grid performance. NERC technical stakeholder groups will continue to evaluate and improve EV charger and EVSE modeling, and NERC will be evaluating ways to enhance collaboration across sectors in the future.

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[27] https://www.nerc.com/comm/RSTC/Pages/LMWG.aspx

[28] Particularly the SAE J2894 committee and their ongoing work in connection with the guidance contained in SAE J2894/1 "Power Quality Requirements for Plug-In Electric Vehicle Chargers."

This document has focused on a specific aspect of EV charging, dynamic behavior in response to grid disturbances. There are numerous other ways in which EV charging will affect grid reliability. Cross-sector collaboration to address the related and separate issues they raise will also be important moving forward. In particular, the detection and exchange of data regarding grid operating conditions as well as the exchange of EV charger data is clearly needed to advance the role of EV charging in supporting and enhancing grid efficiency and reliability. Grid-friendly charging behaviors and patterns (e.g., managed charging or participation in distributed energy resource aggregators) can present significant benefits for providing flexibility services to the interconnected power system. Cyber security considerations and industry and consumer guidance are also important as is the development of education materials for consumers regarding consumer grid friendly charging behaviors. It's important that these areas of collaboration continue in whatever forum is appropriate and capable of attracting the right level of cross-sector stakeholder engagement.

NERC will reach out to EV and EVSE OEMs that have participated in this CMC Working Group to seek input on the best ways to advance recommended EV and EVSE information sharing and collaboration in support of these modeling initiatives. For more information on how to support these efforts, please contact Ryan Quint or Joe Eto.

For more information regarding the CMC EV Grid Reliability Working Group, please contact Mike Walker or Justine Johnson.

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Name	Entity
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Mark Rawson	California Mobility Center
Branden Sudduth	Western Electricity Coordinating Council
Michael Walker	California Mobility Center, EnerTech Capital Partners (WG Co-Chair and Secretary)
Scott Ungerer	California Mobility Center, EnerTech Capital Partners