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Use of Synchrophasors to Transform NEVI EV Charging Stations and Energy Storage into Distribution Grid Nodes

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Executive Summary

The US National Electric Vehicle Infrastructure (NEVI) program, starting in 2023 runs five years, and will fund $5B of 600kW DC fast charging stations (four 150kW chargers) located 50 miles apart on the nation's primary highway corridors [1]. Integrating synchrophasor grid measurements via a micro phasor measurement unit (μPMU) and microgrid controller at the charging station can transform a distribution grid problem into a distribution grid asset and turn NEVI charging stations into microgrid distribution nodes to provide grid services for asset owners, and enable valuable grid visualization for grid operators. Ultimately, NEVI charging stations, along with co-located energy storage and renewables, can enhance grid resiliency and grid stability via microgrid control and ultrafast μPMUs.

Keywords: Ultra-fast Charging, microgrid, smart grid, infrastructure, business model

1 Introduction

Phasor measurement units (PMUs) process grid measurements, called synchrophasors. Synchrophasors are precise measurements of the phase angles of voltage, current, and frequency at nodes on the transmission and distribution grids. Synchrophasors, which are time-stamped and geo-located (via Global Positioning System, or GPS), can be correlated and synchronized against grid activity, and enable grid operators to combine synchrophasor measurements to provide an instantaneous view of the wide grid, which includes system changes and grid stresses. With measurements at 60 samples per second, this is two orders of magnitude faster than supervisory control and data acquisition (SCADA) information systems, which measure once every four seconds. The complete synchrophasor system includes PMU, GPS-synchronized satellite clocks, phasor data concentrator (PDC), communications, and software.

Utilities use PMUs at nodes on the transmission grid as a powerful tool for grid visualization, operations, and forensics for grid disturbances. However, for distribution grids, the power angle is small compared to that of transmission lines, which means that more accurate and precise monitoring is required. Increasingly, micro-PMUs, or μPMUs, are used at nodes on the distribution grid to monitor and control distributed energy resources (DERs) such as renewables, energy storage, and microgrids [2-5].

While microgrids are not a new concept, using μPMUs in combination with microgrid control is relevant for DERs, and especially for a ubiquitous network of high-power EV charging stations sponsored by the US Department of Transportation's (USDOT) National Electric Vehicle Infrastructure (NEVI) program. Thousands of NEVI-class EV charging stations enhanced by energy storage, and renewable generation could play a major role in establishing a new group of resources to provide resiliency, stability, and other services to the distribution grid.

2 The NEVI EV Charging Stations Microgrid Nodal System

To enhance adoption of electric vehicles and fight climate change impacts, the USDOT will work through state DOTs to administer the $5B NEVI program over a five-year period from fiscal year 2022 to 2026, primarily for light duty EVs. Program technical requirements require high-power EV direct current (DC) fast charging stations located no more than 50 miles apart along major state highway corridors. Each charging station will have a minimum of four 150kW DC fast chargers for a total of 600kW minimum power output. This program alone could fund 5,000 to 10,000 NEVI-class EV fast charging stations across the US.

The potential challenges, issues, and opportunities such EV charging stations present are:

- Challenge – High load for a local distribution grid with weak capacity
- Issue – High demand charges from the electric utility
- Opportunity – Provide a network of relatively high-power nodes for local distribution grids, and ultimately the wide grid to supply grid services, grid stability, and grid resiliency

Challenges and Issues – many potential locations along highway corridors are in rural areas with relatively low distribution grid capacity, thus requiring a major upgrade to support a new 600kW load. Even in areas with sufficient grid capacity, electric utilities impose demand charges, which, even at low rates of $5/kW, is a challenge to the EV service provider (EVSP) business model. Both of these challenges often drive the installation of energy storage and local renewable power.

Opportunity – The ideal system would transform a new NEVI-class EV charging station from a distribution grid load into a grid asset that could enhance grid resiliency and stability [6]. One way to do that would be to configure the charging station, energy storage, and renewables into a microgrid. To provide further robust operation and value to the grid operator, the microgrid controller can be integrated with a μPMU. Figure 1 depicts this system.

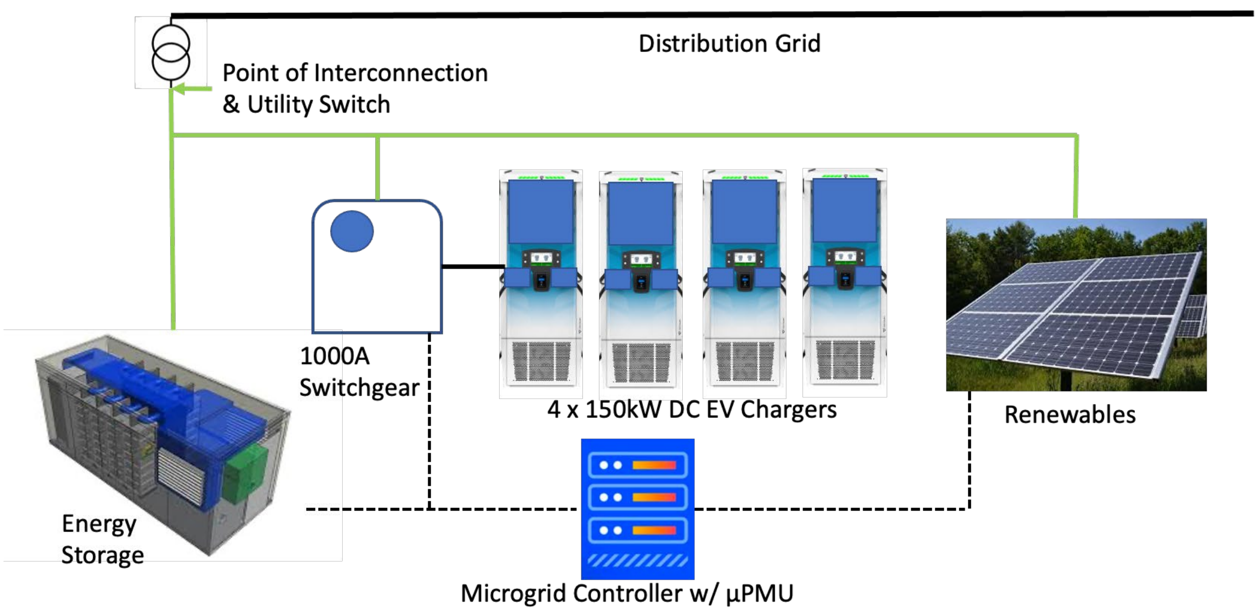

Figure1: NEVI Microgrid 600kW DC Charging Station w/Energy Storage and Renewables

A corridor segment of NEVI-class EV charging stations could be aggregated into a larger system of grid assets and the μPMU data combined and coordinated by the grid operator for grid control (Figure 2).

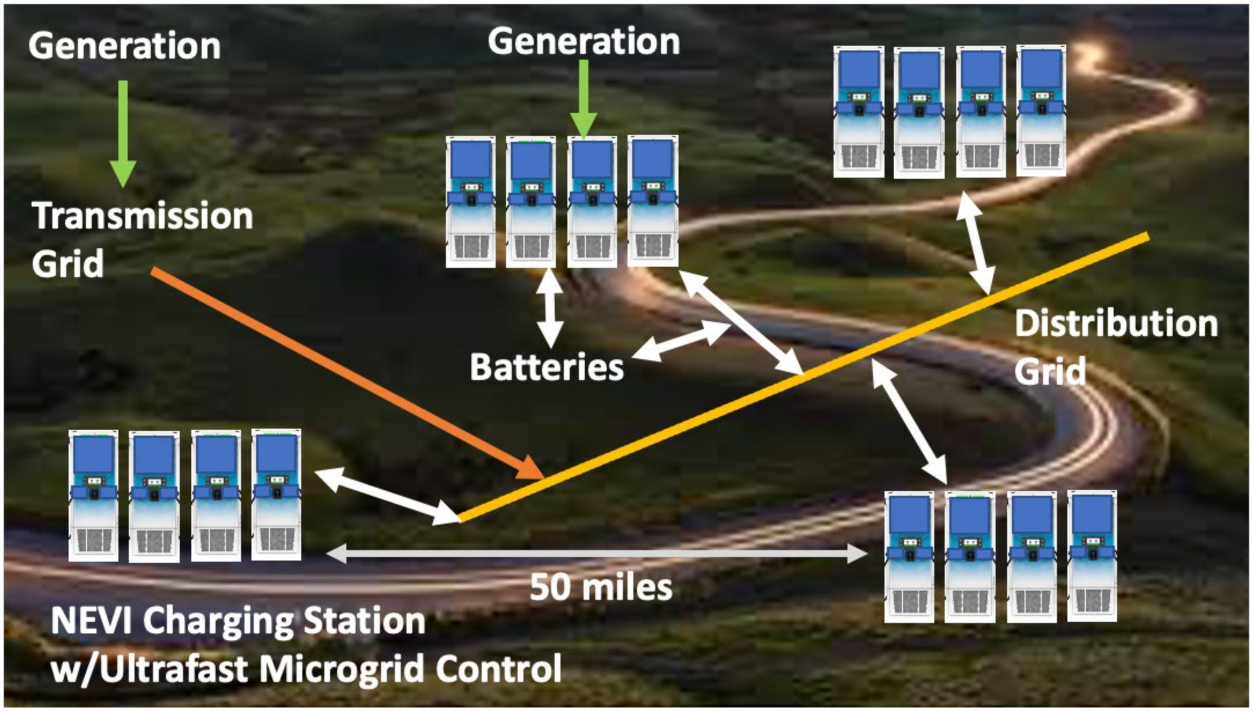

Figure2: NEVI-Class 600kW DC Charging Stations w/Microgrid Control 50 Miles Apart

3 Grid Operator Monitor and Control

Synchrophasor data collected from NEVI EV charging station μPMUs can provide significant situational awareness and remote monitoring for that segment of the distribution grid and contribute to wide area grid visualization [7].

Distribution control systems will be required to handle intermittency issues due to the rapid adoption of charging stations and new incentives for residential and commercial solar generation. The combined variability of these resources requires a new generation of distribution grid controllers. Additionally, disturbances, along with significant loss of inertia from spinning generators, greatly weaken the grid, causing oscillations that without active control, will collapse the grid. This is caused by under frequency and under voltage load shedding systems that have been installed in the distribution grid for years. Grid controllers must estimate and control the distribution grid inertia. This will be accomplished by distributed energy resource management systems (DERMS) controllers that operate at high speed [8, 9, 10]. The controllers will send real time signals to controllable devices in the system: the microgridded EV charging system will be one of those devices. The oscillations in the grid have been studied for many years, and became an active concern as far back as the 1970s.

More powerful and faster DERMS controllers will have the capability to send control signals primarily to microgrids rather than individual DER devices. Thus, having all DER devices inside a microgrid will allow fast and accurate control of real and reactive power flow at the point of interconnection (POI) to the grid.

Clusters of NEVI charging station microgrids, located every 50 miles, can be used in the implementation of the DERMS controllers. These would be organized in a hierarchy of microgrids and would be able to control voltage and frequency of the grid from the bottom up, versus the current top-down method of grid control.

4 EVSP Grid Services

EV chargers can provide reactive power injection, frequency regulation, and other grid services. Energy storage can provide additional grid services for the EVSP that can significantly improve the electric vehicle service provider's (EVSP's) business model. The Federal Energy Regulatory Commission (FERC) order 2222 requires new DER markets be developed for all regions of the US. For example, the Electric Reliability Council of Texas (ERCOT) Fast Responding Regulation Service for the frequency regulation market requires active control intervals of 200 mS or less and a response within 2 cycles. This is much faster control than can be provided by traditional EMS SCADA systems. For EV charging stations with battery and PV, ancillary services and DER markets can provide an additional source of income. Microgrids meeting the Institute of Electrical and Electronics Engineers (IEEE) 2030.7 Standard for Microgrids and tested according to IEEE 2030.8 Standard for Testing Microgrids are ideal for this application. Figure 3 shows an installation of such a microgrid control system with energy storage in a parking stall under a PV canopy.

Figure3: Modular 250kW/650kWh Microgrid System in Single Parking Stall Under a PV Canopy

Neither grid control, nor grid services can be effectively implemented without microgrids directly controlling the flow into or out of the grid. Sending a dispatch order to DERs behind the meter does not allow the power flow to the grid to be controlled due to other loads also behind the meter. With microgrids supervising the loads and sources behind the meter, both real and reactive power can be controlled. This provides the utility the control authority necessary to control the distribution system.

5 A Network of 600kW Stations as a Distribution Grid Asset – Order of Magnitude Versus the Grid

How large a load is a single 600kW EV charging station relative to the grid? Likewise, would a network of such EV charging stations integrated with energy storage and renewables, and configured into a microgrid, make a difference, whether as a load or as a grid asset?

Case 1 – Example of EV charging station planning at a location in central Oregon. An EVSP requested a large investor-owned utility to provide a near-term 300kW electrical service for 2023 and potential additional 300kW for 2024, for a total of 600kW at a city in Oregon near the exit of a major US interstate highway. The utility said it could provide 500kW in 2023, but no additional power until 2025 [11]. This indicates that in some circumstances loads on the order of 500kW can be substantial to a distribution grid.

Case 2 – Example of EV charging station planning at a location in eastern Oregon. A different EVSP requested a different large investor-owned utility to provide a near-term 1MW electrical service in a major city in Oregon, but the utility said it would need to upgrade a substation [12].

Case 3 – Distribution Grid Modeling of Eight EVs Simultaneously Charging [13]. Modeling investigated the impact on four separate distribution grids in Nevada, of varying voltage and capacity, supplying electricity at four different sites for the case where eight EVs would simultaneously fast charge – possible for a NEVI site with four dual port chargers. Results showed that three of the grids (24.9kV) would handle the worst-case NEVI load without difficulty, but the lowest voltage grid (13.2kV), which also had the weakest amperage capacity, might struggle.

The three cases show that EV charging stations on the order of 500kW to 1MW can be significant loads to a local distribution grid. One solution to the problem posed in the above examples would be to install a large energy storage device that charges at a lower electrical service of say, 200kW, but has the capability to discharge at the 600kW peak level when called upon by the EV chargers. This concept would work if the energy storage device could recharge during valleys in charger usage and/or use solar panels to assist recharging. The higher the projected charger utilization, the larger the energy storage device would need to be to avoid running out of discharge power.

The idea of installing energy storage to mitigate EV charger utility demand charges has a positive rate of return only in utility service territories with extremely high demand charges, of say $10/kW. However, if transformer upgrades, switchgear, grid services, and utility benefits are factored in, energy storage can have an immediate positive return on investment. Adding local PV generation to the microgrid could further improve the economics.

The Network Concept

The "grid", both transmission and distribution versions, are highly complex networks of assets meant to balance electricity generation with loads, through a process of tightly orchestrated control of frequency and voltage. For more than a hundred years, electricity generation has been based on central plants that have spinning reserves to help with frequency regulation. This is changing quickly.

These networks of assets rely more and more on a distributed model of generation from wind, solar, and other renewables rather than a central coal or nuclear power plant. This change comes with less spinning reserves to supply grid stability due to decommissioning of fossil plants.

The Owner/Operator Business Model

A logical candidate for owner/operator of EV charging station/microgrids would be EVSPs – e.g., EVgo, Electrify America, EVCS, and Tesla. EVSPs have experience developing sites host agreements, procuring and installing EV charging infrastructure, working with utilities, and most importantly, owning and operating extensive (multi-state) networks of high-powered EV chargers to serve EV drivers.

Also, EVSPs are acutely aware of the challenging economics associated with operation and maintenance (O&M) of DC fast charging stations, and continually look for revenue sources to improve these economics. Although additional capital cost would be associated with the components and energy storage to convert charging stations into hybrid μPMU-enhanced microgrids, the additional revenue has the upside potential to turn a break-even operation into a profitable business.

Utilities could also be owner/operators, but even the largest have only regional service territories (not typically multi-state), have little experience operating networks of DC fast charging stations, and have a customer profile dissimilar to that of EV drivers.

Energy storage not only smooths the variability, but helps with the dispatchability problem attendant with renewables, and also provides grid stability. Energy storage can react within milliseconds for grid frequency regulation, which is much faster than the 15-minute period typical of a natural gas peaker turbine.

One or two EV charging stations with energy storage might not sound impressive as a grid asset. However, a network of distributed 600kW (or greater) microgrids, located every 50 miles could provide a dramatic level of stability, resiliency, and other grid services.

For example, as of February 2022, California had 113 NEVI-class EV charging stations, plans to add another 143 via NEVI funding [14], and will fund even more via State funding, for a total of approximately 500 such potential sites for microgrids. USDOT has approved the NEVI plans of all other states and some territories, which could provide thousands of valuable strategically located, distributed microgrids nationwide.

While the NEVI program is primarily for light duty EVs, federal and state funding is available for medium- and heavy-duty EV charging infrastructure. Charging stations along US highway corridors to serve class 8 heavy-duty trucks could be on the order of 5 to 10MW, which would require a greater role for energy storage to assist in tackling the electrical service problem. Even larger EV charging operations will be associated with overnight charging depots for EV buses, and heavy-duty port drayage vehicles, which could exceed 10MW. Adding these massive charging stations to the networks of NEVI-class charging stations would provide excellent assets for resiliency and grid reliability, whether at the distribution grid level or for the transmission grid.

Energy Storage as Distribution – a Value Proposition for the Utility

The fear is that the adoption of EVs will lead to the need for upgrade of substations and other distribution grid infrastructure. Indeed, high-power EV stations often require transformer upgrades and could lead a potential expensive substation upgrade. However, a network of EV charging stations configured with energy storage and high-speed control via μPMU and microgrid controllers could act as pseudo-generation and potentially delay the need for a substation upgrade [15, 16].

6 Communications and Cybersecurity

IEEE 2030.5 is the communications protocol adopted by the State of California for energy storage, solar inverters, and EV charging. IEEE 2030.5 has been extensively tested by NIST for the purposes of cyber security. This is a client-server messaging system designed specifically to handle secure communications over Internet. One of the largest field deployments of this protocol is in Western Australia. This DERMS system includes remote control of entire towns over Internet.

The PMU communications standard is IEEE C37.118. New streaming telemetry transport protocols are being introduced by IEEE to enable even faster transmission of PMU data over the Internet (IEEE 2664). This is a proven secure protocol using TLS security and very short messages. This protocol may be used for distribution area control systems.

Figure4: Cyber Hacker

Cyber Security – μPMUs can be used to detect and diagnose potential cyber and physical attacks on DER systems [17, 18]. Cyber-attacks are a growing problem as are physical attacks and will lead to increasing DER cyber security requirements [19,20].

7 Conclusions

NEVI-class EV charging stations configured with micro-grid control and enhanced with μPMUs synchronized measurement and control can:

- Provide distribution grid visualization and control at nodes located 50 miles or less apart

PMUs are typically used at the transmission grid level and provide excellent grid visualization, control, and forensics. Extending this to the distribution grid level via expansive use of μPMUs, could bring the many advantages of synchrophasor measurements to much needed DER assets.

- Detect grid events (e.g., outages) and assist with grid resiliency, especially when the charging stations are co-located with energy storage [21]

Grid outages can be devastating to at-risk populations. Detecting grid outages via synchrophasor measurements and providing grid resiliency via energy storage and microgrid control can be lifesaving.

- Provide high value grid services including VAR compensation

VAR compensation, frequency regulation, and demand charge mitigation are just a few of the high-value grid services that a distributed microgrid can provide.

- Enable installation of large loads and large grid assets in regions of relatively weak distribution grids

Installation of energy storage and PV co-located with EV charging is not new, but has always suffered from a poor economic model (i.e., negative rate of return). However, energy storage can enable installation of high-power EV charging stations even in relatively weak distribution grid zones, and do so economically.

- Defer costly distribution grid and potential transmission grid upgrades

One of the economic benefits is to that of the utility if a distribution grid asset (e.g., substation) upgrade can be deferred.

- Provide potential defense against cyber security and physical attacks

High speed μPMU synchrophasor measurements can quickly detect cyber-attacks. Use of IEEE security communication protocols can mitigate and potentially defend against such attacks.

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Presenter Biography

Charles Botsford, PE is a professional chemical engineer in the State of California with 40 years' experience in EV charging infrastructure, energy storage, and environmental management. He participated in California's Vehicle Grid Integration (VGI) Working Group and participates in the Society of Automotive Engineers (SAE) J3072 AC Vehicle-to-Grid, and J3271 Megawatt Charger System standards committees. Mr. Botsford holds a bachelor's degree in chemical engineering from the University of New Mexico, and a master's degree in chemical engineering from the University of Arizona.

Dr. Charles Wells, PE is a professional electrical engineer in the State of California with 40 years' experience in control systems. Chuck has 22 patents on a range of topics including power system optimization, power system load scheduling, decoupling synchrophasor based system for multiple DERS, time synchronized frequency and voltage regulation of electric power balancing areas and many others. Dr. Wells is Chief Technology Architect at PXiSE Energy Solutions based in San Diego, California. Previously, Chuck was at OSIsoft. He received a BS degree from Vanderbilt University and a PhD from Washington University.