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# EVSE Demand Response and Grid Compensation using Synchrophasor Monitoring and Control

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**Abstract**

Electric Vehicle Supply Equipment (EVSE) are residential and commercial devices that use low voltage AC input (typically 208 or 240V in the U.S.) from the grid to charge Electric Vehicles (EVs). EVSE can be equipped with a communications module that allows communication between the EV and the EVSE, as well as between the EVSE and the grid. Increasing grid level communication using synchrophasors, via Phasor Measurement Units (PMUs), which measure voltage, current and frequency at high speeds, could also work in concert with blocks of EVSE to provide demand response and grid compensation functionality. When combined with energy storage, this also enables the potential for increased renewables grid penetration.

To increase the widespread use of EVs, the deployment of EV charging infrastructure in the form of EVSE is critically important. However, many obstacles relative to infrastructure capital and installation costs, and perceived impacts to the grid must first be overcome. This paper addresses EVSE grid impact mitigation measures as well as grid services EVSE may provide.

*Keywords: Level 2 EVSE, Electric Vehicles, demand response, Synchrophasors*

## 1 Introduction

You've just bought an Electric Vehicle (EV) and your auto dealer says you should install a charger in your garage to provide a convenient way to charge your new EV. This charger is called Electric Vehicle Supply Equipment (EVSE) and allows 208V or 240VAC power to flow from the grid to your brand new EV's on-board charger via a set of contactors.

Enabling the functionality of these EVSE contactors, are elaborate software, connectors and communications protocols. The EVSE can be thought of as the gateway between the grid and the energy storage device on board the EV (i.e., the EV battery.)

This paper describes a potential control strategy for a block, or aggregate of EVSE, using a monitoring and control technology called, Phasor Measurement Units, or PMUs. The outputs from PMUs, when equipped with Global Positioning Satellite (GPS) technology are called, Synchrophasors. This paper is organized to describe:

- Problem overview
- EVSE and control
- Communications between the EVSE and the EV
- The EV battery and on-board charger
- Time-of-use rates and Demand Response
- Energy storage
- Synchrophasors and associated issues such as Supervisory Control and Data Acquisition (SCADA) and cyber security challenges
- Grid control strategies for residential EVSE
- Grid control strategies for non-residential EVSE
- Conclusions

### 1.1 Problem Overview

Today, electric utilities worry whether neighborhood transformers, whose normal duty cycle allows them to cool down overnight, will hold up to the additional use brought on by overnight EV charging. They also worry that EV charging during peak grid usage could negatively impact grid stability. This paper focuses on how to use EVSE, EVs and advanced monitoring / control equipment in concert as a control strategy to provide grid ancillary services. The potential benefits of this control strategy are:

- Provides ancillary grid services to the electric utility
- The electric utility provides lower electricity rates or rebates to EVSE owner/operators for these services
- Provides a degree of transformer wear mitigation
- Provides a mechanism to increase renewable energy penetration to the grid

Among the obstacles to implement such a control strategy are:

- Communications and control protocols and standards development
- Equipment and labor costs for implementation
- Initial availability of EVs
- Data management and control development

# 2 EVSE and Control

EVSE charging stations monitor AC power before and during the charging process to ensure safe transfer of power to an EV or Plug-in Hybrid Electric Vehicle (PHEV). Manufacturers provide them in a number of configurations. Residential applications primarily use wall-mounted units, while non-residential applications primarily use pedestal units. Figures 1 and 2 show wall-mount and dual-port pedestal EVSEs.

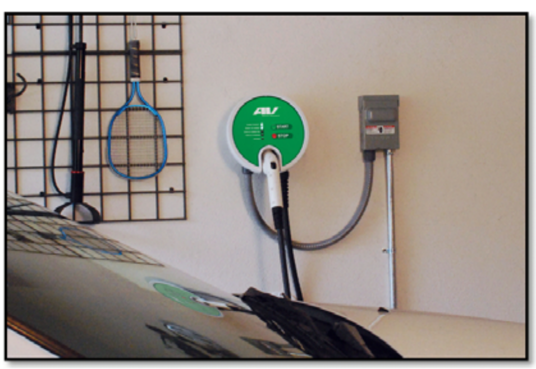

Figure 1: Residential Wall-Mount EVSE

Figure 2: Workplace Dual-Port Pedestal EVSE

The EVSE central control unit controls the main contactor, monitors the safety systems and provides the communication pilot signal to the vehicle. When a vehicle is connected and proper charging conditions have been established, the contactor closes allowing power to flow to the vehicle.

## 2.1 Communications Between the EV, EVSE and the Grid

In the United States, the Society of Automotive Engineers (SAE) is developing a set of protocols for communications between the EV and the EVSE and between the EVSE and the grid [1]. These protocols work in concert with the standard EVSE cable and connector governed by the SAE J1772 standard. These protocols are:

- **J2836 –** Use cases for communication between plug-in electric vehicles (PEVs) and the electric power grid, for energy transfer and other applications.
- **J2847** – Requirements and specifications for communication between PEVs and the electric power grid, for energy transfer and other applications.
- **J2931 –** This is intended to complement J1772 but address the digital communication requirements associated with smart grid interoperability.
- **J2953 –** Supports digital communication requirements within J2836 that includes the use cases and general information for several communication approaches and J2847 that includes the corresponding detail messages and state diagrams.

## 2.2 The EV Battery and On-Board Charger

As of 2012, almost all PEV original equipment manufacturers (OEMs) supplied on board chargers that were unidirectional, not bi-directional. This means PEVs on the market or currently planned for introduction use on-board chargers that accept power from the grid, but cannot supply power back to the grid.

The bi-directional flow capability is also known as vehicle-to-grid, or V2G flow. The on-board charger converts AC power from the EVSE to DC power to charge the battery. For bi-directional flow, the on-board charger would have to accept DC power from the battery and invert it to AC power to send to the grid. This bi-directional capability adds cost, weight, volume and reliability issues to the basic unidirectional on-board charger, which is why almost no OEMs currently provide V2G capability. Unidirectional flow with control signals for the grid provides much of the same functionality as V2G, but at a lower capacity.

The EV battery's battery management system (BMS) controls how the battery is charged. The BMS measures such parameters as state of charge (SOC), cell temperatures, and also balances the battery cells to maintain battery life. The BMS tells the on-board charger to stop charging if the SOC approaches 100% or if the battery temperature is too high. It also tells the on-board charger it can and will accept electricity (DC power.) Thus, the EVSE typically acts to signal the available charging current to the on-board charger.

## 2.3 Time-of-Use Rates and Demand Response

Time-of-Use pricing (TOU) allows electric utilities to price electricity according to the time of day and value of grid electricity at the time. Electric utilities have, and are in the process of applying the TOU pricing technique to modify the behavior of residential, commercial and industrial customers to charge during off-peak hours.

Electric utilities use Demand Response as a more active technique than TOU to curtail loads when necessary, to provide grid stability. EVSE can be controlled with approximately the same sophistication as residential air conditioning and clothes dryers.

TOU and Demand Response are discussed here to complete the picture of control techniques for EVSE chargers—from advanced technical control to fiscal control.

# 3 Energy Storage

Traditionally, the grid has had little energy storage capacity. Electricity generation must closely match load in real time, which means generation must be ramped up and down from the baseload to meet peak requirements, typically through the use of natural gas-fired "peaker" turbines.

Grid level energy storage may serve the same function, while also providing grid ancillary services and the capability to allow increased renewables penetration, especially during off-peak hours. Grid level energy storage has many potential applications of use to grid operators, such as frequency regulation, peak shaving and peak shifting. Of these, frequency regulation and peak shaving appear to provide the highest value.

Grid power flows to and from energy storage. If the energy storage device or aggregation of devices is thought of as a system node, then monitoring this power flow in essentially real time, using devices such as the phasor measurement units (PMUs) described below, may provide data on grid voltage, frequency, phase angle and other parameters.

PEVs, in sufficient numbers, may be considered a form of grid level energy storage. In its simplest form, control of PEV energy storage is likely to be one way (unidirectional) flow from the grid to an aggregation of PEVs via EVSE.

## 3.1 The EV Battery

PEV battery capacities range from a few kWh to more than 50kWh.

Alone, the energy storage capacity of these batteries for use to provide grid services is insufficient. However, the coordinated capability of hundreds, thousands, or millions of EVs has the potential to provide robust grid services. The control, whether the individual EV, or in blocks of multiple EVs, is discussed later in this paper.

## 3.2 Community Energy Storage

Community energy storage (CES) refers to a concept popularized by American Electric Power (AEP). The idea is to provide energy storage to reduce peaks during daylight hours, which reduces the load for the neighborhood transformer. This could alleviate the potential for degradation from a cluster of EVs charging at night. CES nominally provides 25kW of power with 50kWh of storage.

# 4 Synchrophasors

## 4.1 Background

Electric utilities monitor grid conditions primarily with supervisory control and data acquisition (SCADA) systems. A full scan of system devices can require two to ten seconds for a SCADA system. However, because SCADA has low sample rates and provides asynchronous measurements to the state estimator, the data are not normally useful in fast responses for controlling grid problems [2,3,4].

Synchronized phasor measurements, or Synchrophasors, are measurements taken by phasor measurement units (PMUs) of the phase angle of voltage, and other state variables at high rates of 30 observations per second. In viewing the grid from a system-wide perspective, this enables much tighter grid control, real-time analysis, and forensics for outages. PMUs are installed at a number of locations, including substations. Phasor data concentrators, or collectors (PDCs), combine and process the information from many PMUs, which is then transmitted to the central control unit. The PMU function can also be incorporated into protective relays or other devices, making this a particularly powerful monitoring and control technique.

Synchrophasors can also provide data for the much slower SCADA systems to enhance state estimation. As demand response at the residential and commercial device level grows and as grid services become more pervasive with the growth of energy storage, the need for a more integrative approach between local and system-wide grid monitoring/control, and device management becomes clear.

PMUs were introduced in the 1980s and have gained widespread popularity and use for such applications as congestion analysis, operations planning and state estimation [5]. Synchrophasors, via PMUs allow grid operators to bring on line a crucial aspect of the Smart Grid at the grid system level. Many other applications, such as automated real-time control of assets, power system restoration, and dynamic and static model validation are also in use.

## 4.2 Synchrophasors and Energy Storage

With the ability of the Smart Grid to monitor assets and grid health via PMUs, if a feeder line were to exhibit congestion, voltage sag or other issue, a grid controller could automatically signal grid energy storage, whether and aggregation of EVs, CES or larger energy storage device to increase or reduce charge power level appropriate to the control scheme.

PMUs allow grid operators to apply many types of system asset control. This can allow identification of assets that can respond in real-time to local grid problems. For existing grid assets with phasor measurement technology, synchrophasor functionality may be added to provide increased control. Conceivably, adding synchrophasor functionality, and voltage and current inputs/filtering to a CES or other grid level energy storage system has the potential to turn a grid load into a valuable compensation asset. Also, PMUs could be distributed over wider areas to monitor energy storage nodes.

## 4.3 Cyber Security

This paper does not list cyber security strategies or philosophies in detail. However, designing a grid level control system requires consideration of data transfer and vulnerability. For example, if a control function can be performed by pushing a signal, and confirmation of control success can be confirmed without a feedback signal, then one level of communication attack vulnerability has been mitigated. This philosophy may have grounding in the inherent simplicity of control strategies discussed below.

# 5 Grid Control Strategies

## 5.1 Use of Synchrophasors for Distributed Generation Control – PV and Wind

The following two examples are applications of PMUs for distributed generation monitoring and control. These are listed only to demonstrate the rapidly increasing use of PMUs away from traditional grid-wide phasor measurement applications.

**Photovoltaics (PV).** One issue associated with distributed generation (DG) assets is islanding and anti-islanding. In brief, when the grid distribution system goes down, or a DG source is islanded from the grid, the DG source must disconnect from that portion of the grid within two seconds according to the Institute of Electronics and Electrical Engineers (IEEE) 1547. Synchrophasors have demonstrated the capability to act as a "Smart" islanding and anti-islanding technique for a 100kW photovoltaic (PV) generation system in Oregon [5]. This demonstration is important because traditional methods that use only local measurements may not detect islanding soon enough for all load/generation conditions.

**Wind.** More and more, the use of energy storage in conjunction with wind farms helps stabilize fluctuating power generation. A synchrophasor measurement system (two PMUs with a PDC) monitors a two-terminal line at Austin, Texas and a wind farm several hundred miles west of Austin. The system processor provides output of relative phase angle and frequency variations, which allows feedback control of energy storage and enables grid operators to monitor impacts [6].

## 5.2 EVSE Control

Also for practical purposes, a block of EVSE may prove more practical to control via grid signal rather than individual signals to individual EVSE. The Federal Energy Regulatory Commission (FERC) provides rules and guidelines for energy market services [8]. A US Department of Energy Report [9] indicates a minimum of 100kW may be required to qualify for entry in some markets. This would be equivalent to a group of 15 or more EVSE rated at 6.6kW. Viridity and Axion Power announced in November 2011 participation in Pennsylvania/Jersey/Maryland Power Pool (PJM) regulation market, stating a projected value ranging from $180,000 to 240,000 per MW of delivered generation [10]. For a 100kW source this would be $18,000 to 24,000/yr. Translation of this value to EVSE would be misleading because of the typically low EVSE capacity factor.

The following figures show notional block diagrams for residential and non-residential EVSE with energy storage and PMU monitoring and control.

Block control based on aggregating a relatively large number of EVSE is a probabilistic venture requiring individual EV owner permission. EVSE owners will want control over how they charge their EVs. For this reason, they will want the right to grant permission for EVSE use by a third party for grid services. Some EVSE owners may never want the utility to have control over their EVSE. Some may grant permission for use under special circumstances. Some may be liberal in granting permission for use. Of course, the SAE communication protocols listed in Section 2 play an important role in the monitoring and control structure.

To accumulate a 100kW source that can be counted on for grid services, a block of 15 EVSE at 6.6kW will likely not be adequate. In fact, the block may require 50 EVSE to satisfy utility requirements.

The figures depict control of EVSE at either the energy storage device level or area transformer for both residential and commercial settings. Feeder line control algorithms would react to grid problems (e.g., voltage sags, frequency drops) and provide control to (1) decrease EVSE charger power draw through communications to the EV, (2) increase power from the energy storage to the grid, (3) provide power to the grid from the vehicle battery, or (4) combination of 1 through 3. For the reverse grid upset (e.g., frequency increase), the line controller would (5) signal the energy storage to draw power or (6) signal the EV charger to draw power at the maximum rate it requires to charge the EV.

## 5.3 Residential Control

Block control in 100kW increments may not be critical for residential EVSE. This is because the electric utilities may treat the EVSE as demand response devices much the same way they treat air conditioners. They could also provide special rates for EVs. In either case the rate benefit would likely be at the individual EVSE owner.

A notional block diagram for residential control is shown in Figure 3.

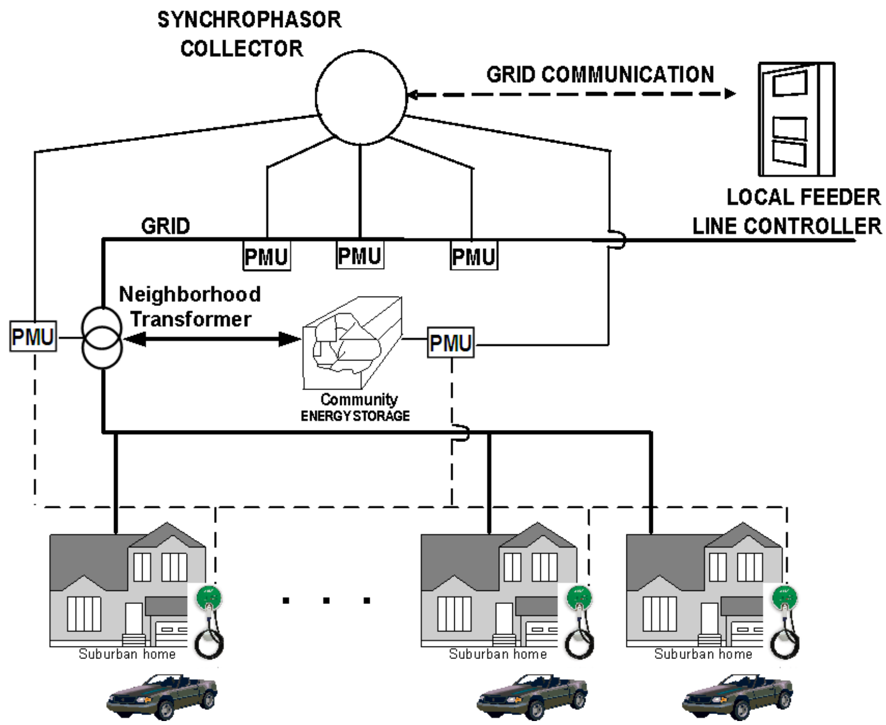


Figure 3: Residential EVSE Demand Response and Grid Compensation via PMUs

## 5.4 Non-Residential Control

Block control will likely be critical for non-residential use because of TOU issues. For example, workplace and public venue charging could easily take place during peak use hours, while residential charging is likely to take place during early morning, low electrical use hours.

Individual autonomous EVSE control could form the baseline control scheme and would be relatively secure from cyber attacks because of the monitoring node control aspect and also because of the permissive nature of the EVSE use.

Collective block control would also be relatively secure from cyber attack because of the one-way, top down communication combined with permissive EVSE use.

A notional block diagram for non-residential control is shown in Figure 4.

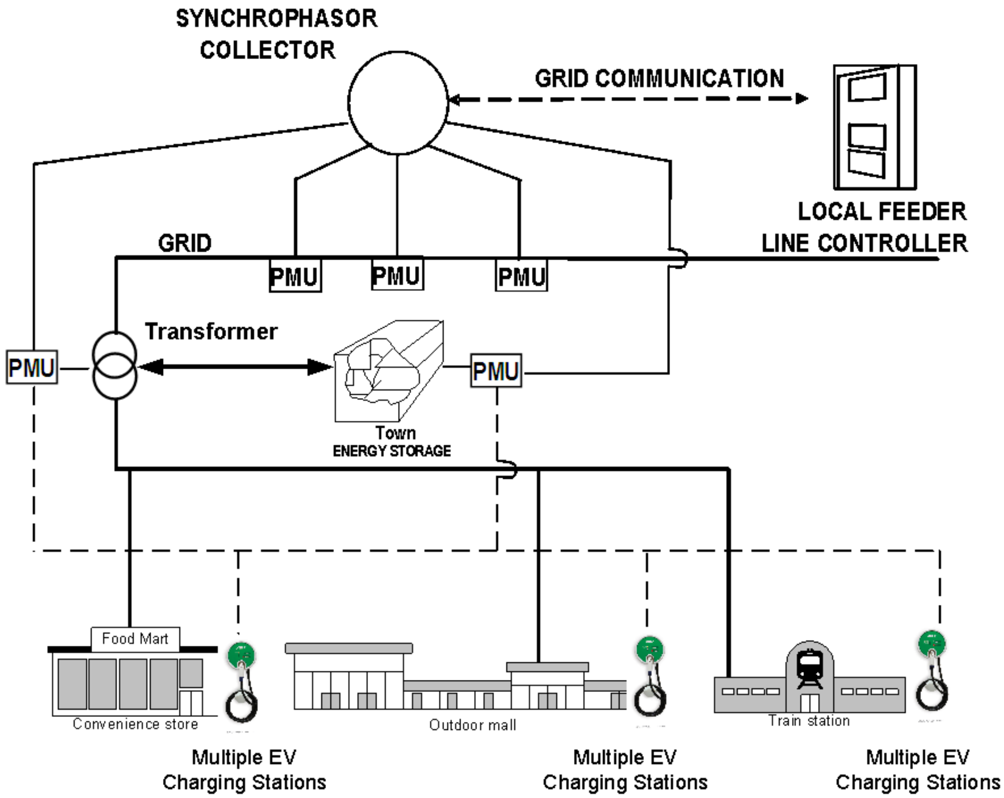


Figure 5: Commercial EVSE Demand Response and Grid Compensation via PMUs

## 6 Conclusions

The technology to transform the EVSE/EV battery system, a grid load, into a valuable grid asset, exists in the form of components and a system approach that includes PMUs and grid-level energy storage.

Already, PMUs and Demand Response are making great strides as key components to enable the smart grid paradigm. Electric utilities and EV stakeholders are conducting widespread demonstration programs and application testing for TOU pricing, grid-level energy storage, grid power electronics, synchrophasors and EV charging infrastructure.

This paradigm has the potential to provide electric utilities a level of control of incremental generation capacity not available with the much slower and limited capability SCADA systems.

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