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Evaluation of ground energy storage assisted electric vehicle DC fast charger for demand charge reduction and providing demand response

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A R T I C L E I N F O

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A B S T R A C T

In 2012 there was approximately 2400 electric vehicle DC Fast Charging stations sold globally. According to Pike Research (Jerram and Gartner, 2012), it is anticipated that by 2020 there will be approximately 460,000 of them installed worldwide. A typical public DC fast charger delivers a maximum power output of 50 kW which allows a typical passenger vehicle to be 80% charged in 10–15 min, compared with 6–8 h for a 6.6 kW AC level 2 charging unit. While DC fast chargers offer users the convenience of being able to rapidly charge their vehicle, the unit's high power demand has the potential to put sudden strain on the electricity network, and incur significant demand charges.

Depending on the utility rate structure, a DC fast charger can experience annual demand charges of several thousand dollars. Therefore in these cases there is an opportunity to mitigate or even avoid the demand charges incurred by coupling the unit with an appropriately sized energy storage system and coordinating the way in which it integrates. This paper explores the technical and economical suitability of coupling a ground energy storage system with a DC fast charge unit for mitigation or avoidance of demand charges and lessening the impact on the local electricity network. This paper also discusses the concept of having the system participate in demand response programs in order to provide grid support and to further improve the economic suitability of an energy storage system.

1. Introduction

A typical DC Fast Charge (DCFC) unit delivers a maximum power output of 50 kW, allowing for a Plugin Electric Vehicle (PEV) the ability to be 80% charged in 10–15 min, compared with 6–8 h for a 6.6 kW level 2 AC Electric Vehicle Supply Equipment (EVSE) unit. Given this rapid charge nature of a DCFC, the units place large power demands on the local electricity grid, with a very short ramp up period (approximately 5 s). While there were approximately 2400 DCFC units sold in the world during 2012, it is anticipated that by 2020 there will be approximately 460,000 of them installed worldwide [1].

One of the factors that hinder the widespread rollout of DC Fast Charge (DCFC) units is that for connections at this power level, many electric utilities impose demand charges that range from $5[1] to $30 per kW per month, which can in fact dominate a utility bill in certain circumstances [2]. A generic example of the effect of demand charges on a utility bill is shown below in Table 1, where the bills for a varying number of charged PEVs are shown along with the cost per vehicle charged. In this example, the basic meter charge is $200 (regardless of the power and energy drawn by the DCFC); the demand charge is $10/kW, a typical commercial value; and the energy charge is $0.11/kWh, also a typical commercial value. Each PEV that is charged is assumed to use the full 50 kW available from the DCFC for 20 min, for a total energy usage of 20 kWh per vehicle. A further assumption is that there is no other load on this particular meter. Implicit in this assumption is that a new utility service is installed for the EVSE,

Abbreviation: CHAdeMO, DC fast charging protocol; DCFC, Direct Current Fast Charge; DR, Demand Response; ECS, Energy Curtailment Specialists; EV, Electric Vehicle; EVSE, Electric Vehicle Supply Equipment; GES, Ground Energy Storage system; ISO, Independent System Operator; PEV, Plugin Electric Vehicle; PG&E, Pacific Gas and Electric; RTO, Regional Transmission Organization; RTP, Real Time Pricing; SAE, U.S. Society of Automotive Engineering; SDG&E, San Diego Gas and Electric; SOC, SOC State of Charge; TEP, Tucson Electric Power; TEP, Tucson Electric Power; TOU, Time of Use; TVA, Tennessee Valley Authority; V1G, Demand only control of Vehicle to Grid; V2G, Vehicle to Grid.

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[1] All monetary amounts are in USD.

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Table 1
Demand charge scenarios.

Scenario	Number of vehicles charged/ month	Meter charge	Demand charge	Energy charge	Monthly total	Cost per vehicle
1	0	$200	$0	$0	$200	N/A
2	1	$200	$600	$2.20	$802.20	$802.20
3	10	$200	$600	$22	$822	$82.20
4	100	$200	$600	$220	$1020	$10.20
5	250	$200	$600	$550	$1350	$5.40
6	500	$200	$600	$1100	$1900	$3.80

and that the additional costs associated with a new service for the DCFC are ignored.

As shown in Table 1, the demand charge remains constant regardless of the number of vehicles charged, and that it becomes proportionally less of the bill as the number of vehicles charged increases. Furthermore, as the number of vehicles charged increases, the overall cost per vehicle falls dramatically. If a sufficiently large number of vehicles use the EVSE to charge, the demand charge becomes less of a concern. However, since the number of vehicle customers cannot be estimated with any precision and the site owners may be unwilling to incur large demand charges, strategies to reduce or eliminate these charges must be developed.

2. Coupling a ground energy storage system to an electric vehicle DC fast charger

2.1. Overview of the system

In order to buffer the high instantaneous power demands of a DCFC unit, a Ground Energy Storage system (GES) can be coupled with the DCFC unit to assist during a recharge event, and reduce (or eliminate) utility demand charges. As shown in Fig. 1, the arrangement allows for the GES to supply some or all of the power and energy needs of the DCFC when charging a PEV. The GES can then be recharged at or below the power demand threshold to minimize or eliminate power demand charges, and/or during off-peak time periods when energy prices are at their lowest.

The performance capability of the GES is dependent on the selected energy capacity (in units of kWh) and instantaneous power rating (in units of kW) of the system. While it would be desirable to minimize the total cost of the system, the following points need to be determined in order to calculate the necessary capacity and rating of the unit:

- **Discharge time and energy for one vehicle charge** – Determined by the size and charge logic of the PEV battery.
- **Number of back-to-back charges** – Determined by the customer use of the DCFC.

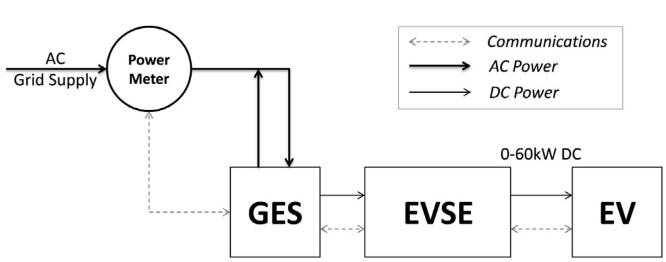

Fig. 1. GES assisted recharging of EVSE unit.

- **Time to recharge the GES for one vehicle discharge** – Determined by the charging logic of the GES and the grid power supply.
- **Time to recharge GES from empty** – Determined by the charging logic and the size of the GES as well as the grid power supply.

It follows then that DCFC units with lower use and fewer back-to-back charges will also require a smaller-capacity GES, which subsequently will be cheaper. Fig. 2 depicts an example of the demand curve of a DCFC over the course of 12 h, and the subsequent capacity curve of the GES and demand curve seen by the AC grid as they combine to supply the DCFC. In this example, the GES has a usable capacity of 20 kWh and a discharge rate of 30 kW, in order to keep the instantaneous demand on the AC grid supply less than or equal to 20 kW, for a 50 kW DCFC.

When determining the cost of a GES, there are two main modules – the power electronics and the battery – which dictate the price of the unit and are dependent of the kW and kWh requirements determined from the points mentioned before. The following are current approximate costs for each module (prices for U.S. in USD), with 100% mark-up likely for a complete GES purchased ready for installation.

- Inverter module and Power electronics – $300/kW
- Battery:
  - Lithium-ion (Li-ion) type – $1000/kWh
  - Lead type – $500/kWh

As an example, a GES that is required to deliver 30 kW of discharge, has a 20 kWh Li-Ion battery, and is ready for installation could cost $58,000 ($29,000 plus the 100% mark-up for overheads to bring the product to market). The ability to offset the cost of such a system would then be dependent on the annual savings in demand charges, and the required payback period. It could be anticipated the at Li-Ion system would have an operational life expectancy of approximately 7–9 years, and a lead-based system would be approximately 3–5 years. Using the $58,000, 30 kW 20 kWh Li-Ion system example described above, Table 2 compares the required annual saving in demand charges for a desired payback period to be achieved.

When considering a GES for assisting a single DCFC, the 30 kW rate of discharge would be quite typical given that there are a large number of utilities in the U.S. which impose demand charges for 50 kW connections, but also have a rate available for ≤20 kW for which no demand charges would be imposed. Table 3 provides a comparison of what the potential annual savings in utility charges can be by installing a GES and reducing the peak demand from 50 kW to 20 kW for a DCFC that uses 7016 kWh per year.

In the arrangement shown in Fig. 1, there is a direct communications link between the DCFC and the GES. This communication link is necessary so that when a charge event begins, the GES can determine whether there is sufficient stored energy to complete the charge.

- For a CHAdeMO DCFC, a change in maximum charging current cannot occur mid-charge, so the DCFC will have to be limited to the maximum allowed AC grid instantaneous power from the beginning of the charge [3].
- For a SAE J1772 DCFC, a change in maximum charging current can occur mid charge [4]. The DCFC will therefore be supplied at the full 50 kW instantaneous power rating, until such time that the GES has been depleted. At this moment, the DCFC maximum charging power will then be reduced to the maximum allowed AC grid instantaneous power for the remainder of the charging event.