BATTERY-POWERED, ELECTRIC-DRIVE VEHICLES PROVIDING BUFFER STORAGE FOR PV CAPACITY VALUE

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ABSTRACT

The use of batteries to provide storage for photovoltaic (PV) power has been evaluated in various contexts. In grid-connected applications, batteries can serve to provide firm peak-shaving for distributed PV installations. To date, however, the use of batteries from parked electric-drive vehicles (EDV) to provide buffer storage for PV capacity value has not been analyzed. The emerging vehicle to grid (V2G) concept suggests that battery-powered EDVs can provide power to the grid to serve various markets. This paper evaluates the use of battery-powered EDVs to provide buffer storage for grid-connected PV installations, assuming a V2G infrastructure. The approach could serve to provide capacity value for PV installations, thus enhancing their value as distributed, demand-side resources.

1. INTRODUCTION

Air quality issues associated with tailpipe emissions from automobiles are extremely serious in certain regions of the United States. Ground-level ozone in major U.S. cities imposes serious and costly health impacts on humans and other living organisms. Many analysts view electric drive transportation as key to addressing urban, air quality issues; this includes battery-powered, fuel cell, and hybrid vehicles.

At the state level, California is leading the nation in setting guidelines that require all major automobile manufacturers to sell a certain percentage of total sales that qualify for zero emission vehicle credits. Several eastern states are following California's lead, where guidelines have changed to allow vehicles with low and ultra-low emissions to qualify for zero emission vehicle (ZEV) credits

The California Air Resources Board (CARB) has developed ZEV requirements that will result in a number of new battery-powered electric drive vehicles being sold beginning in 2003. It is expected that CARB guidelines will result in the sale of approximately 4,650 battery-powered EDVs [1]. The total energy storage potential of annual battery-powered EV sales should be around 100 MWhs starting in 2003; this will increase overtime as the CARB guidelines call for increased sales of vehicles in proceeding years qualifying for ZEV credits.

Technological developments, reduced costs, and various policies, including net metering and buy-down programs, have lead to a proliferation of grid-connected PV installations across the country. The Sacramento Municipal Utility District (SMUD) alone has installed over 1.5 MW of rooftop PV [2]. These systems generate value primarily through the energy produced and fed into the local grid. While the capacity value of PV has been demonstrated [3], market structures and the intermittent nature of the solar resource create challenges to realizing the capacity value of PV installations. This paper analyzes the potential role that battery-powered EDVs could play in providing buffer storage for distributed PV installations. Battery-powerd EDVs can technically serve as buffer storage for PV installations creating firm capacity value, which could potentially enhance the economic value of PV in energy markets.

2. THE VEHICLE TO GRID (V2G) CONCEPT

As stated above, ZEV mandates will result in the sale of battery-powered EDVs in states pursuing this policy approach. These vehicles will require an infrastructure to accommodate charging from the grid. This same infrastructure could be used, at little additional cost, to accommodate power flowing from vehicles to the grid, referred to throughout this paper as vehicle-to-grid (V2G) power. In a recent press release, the Electric Power Research Institute speculates that V2G could reduce the requirement for global, central-station generation capacity by up to 20% by the year 2050 [4].

Previous investigations into the V2G concept suggest that parked, battery-powered EDVs can provide peak power and ancillary services at a cost to the vehicle owner that is lower than the potential revenues from selling these serves in energy markets [1] [5]. Furthermore, Kempton and Letendre [6] suggest that battery-powered EDVs could serve as a bridge for integrating intermittent energy resources into the nation’s grid.

There are no significant technological barriers to the implementation of the V2G concept. In fact, the California Independent System Operator (ISO) is demonstrating the idea using a new VW Beetle EDV concept car outfitted with remote, wireless dispatch capabilities and a bi-directional battery charger manufactured by AC Propulsion Incorporated [7]. This vehicle is being used by the CAISO to provide ancillary services to the California electric grid, such as regulation services.

However, for the V2G concept to be implemented on a large scale, coordination is required across different regulatory agencies and industries. In California, the Air Resources Board has adopted an on-board conductive charging standard for all new charging stations, citing the ease of adapting to V2G as one reason. However, market rules and technical requirements for participating in competitive markets for ancillary services and power must be evaluated to determine potential barriers to the implementation of the V2G concept. Some degree of coordination is also required between the electric utility sector and the automobile manufacturing sector. Vehicles manufactured with V2G capabilities must meet utility standards with regard to grid interconnections and on-board metering. Furthermore, as discussed later in this paper, for PV installations to realize potential capacity values using EDVs for buffer storage, coordination between V2G developers and PV system owners will be necessary.

3. EDVS ANALYZED

There are three types of electric drive vehicles that could provide V2G power: hybrids, battery-powered, and fuel cells. Of these vehicle types, we focus our analysis on battery-powered EDVs. These vehicles represent a near-term opportunity and avoid some more complex technical issues.

Hybrid vehicles, using both gasoline and electric motors, have rather limited on-board energy storage capacity. The Toyota Prius has only 1.8 kWh of energy storage and the Honda Insight only 0.9 kWh of energy storage. Fuel cell vehicles, which many view as a longer-term option, power an electric motor through a hydrogen-based electrochemical process. Early fuel cell vehicles will likely obtain hydrogen through reforming traditional fuels, such as gasoline or natural gas.

These vehicles can provide V2G power and thus serve as buffer storage. With these types of vehicles, the on-board fuel could serve as buffer storage. However, the more complex controls to provide V2G power and issues associated with managing waste heat and exhaust fumes create challenges in using these vehicles for buffer storage. As a result, the analysis presented in this paper focuses exclusively on battery-powered EDVs.

3.1 Battery-Powered EDVs Analyzed

Three different battery-powered EDVs configurations are analyzed: lead-acid prototype, Honda EV Plus, and Ford Th!ink City. The Honda EV Plus was mass-produced but is no longer in production. The Ford Th!nk is currently in production, and the characteristics of the lead-acid prototype are based on a design by AC Propulsion. Table 1 provides the key technical characteristics of each vehicle analyzed.

TABLE 1: TECHNICAL CHARACTERISTICS OF VEHICLES ANALYZED

	Pb-acid prototype	**Honda EV Plus**	**Ford Th!nk City**
battery type	Pb-acid (66 Ah)	NiMh, (95 Ah)	NiCd (100 Ah)
energy stored	23.8 kWh	27.4 kWh	11.5 kWh
max range	80-100 miles	80-100 miles	53 miles
battery cycle life	1,000 cycles	1,000 cycles	1,500 cycles
efficiency (round trip)	74%	72%	80%

(Source: Kempton et al., 2001)

Each of these vehicles described in Table 1 above could, if connected to a V2G portal, provide buffer storage for grid-connected PV installations. Any V2G application must take into consideration parameters set by the vehicle owner, which serve to limit use of the stored energy in the vehicle so as to not impinge on the owners perceived transportation needs. V2G controls must allow the vehicle owner to input anticipated driving requirements to limit discharge from their vehicle's battery bank. Figure 1 illustrates the potential storage remaining taking into consideration depth of discharge and a range of assumptions regarding the vehicle owners' range buffer requirements.

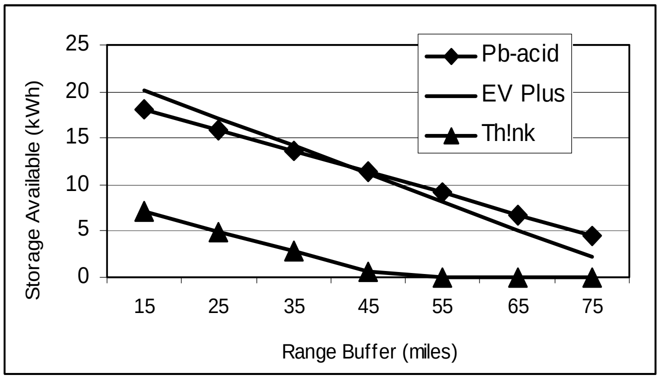

Fig. 1: Available Energy for Buffer Storage vs. Owner Range Requirements

Figure 1 clearly demonstrates that the amount of buffer storage in each of the EDVs analyzed is directly related to the vehicles owner's stated needs for a range buffer. The more driving the vehicle owner anticipates doing, the less energy available for buffer storage. For the Pb-acid prototype and the EV Plus, even with a 50-mile range buffer, there is still over 10 kWh of storage available in the vehicles' battery banks.

4. PV CAPACITY AND BUFFER STORAGE

Battery storage is a standard requirement for off grid PV applications. However, the need for battery storage for grid-connected applications is less clear. Net metering in essence allows PV installations to in-effect use the grid as storage, dumping excess power produced during the day into the grid, spinning the meter backwards. However, some studies have suggested that a modest amount of battery storage can enhance the peak-shaving value of grid-connected applications [8] [9]. As described above ZEV mandates will result in a significant amount of battery storage, purchased for transportation services, will be connected to the grid beginning in 2003. This study investigates the use of this storage to provide buffer storage for grid-connected PV applications.

4.1 Minimum Buffer Storage Requirement

Perez et al. [3] have utilized satellite-derived solar resource data to calculate different measures of PV capacity for most utility service territories across the nation. For example, a measure of PV capacity, called the effective load carrying capability (ELCC), was calculated for most U.S. electric utility service territories; ELCCs for PV approach 75% in certain utility districts serving large, urban loads.

Another related measure of PV capacity developed by Perez et al. is the minimum buffer energy storage (MBES), which is defined as the minimum amount of stored energy required in association with the PV system, to guaranty, in the case of a demand-side management, a firm peak load reduction equal to the rated capacity of the PV system [10]. A measure of system hours is used to quantify the buffer storage requirement. In California the MBES at a PV penetration rate of equal to or less than 5% of system peak ranges from 0.75 – 1.00 system hours.

Matching PV with an amount of energy storage as indicated by MBES thus qualifies the PV system for firm, capacity credit as a demand-side resource. In the case of California, a PV system rated at one MW would require between .75 and 1 MWHs of buffer storage to provide firm capacity equal to the one MW rated capacity of the system.

This approach to establishing PV's capacity value differs from methods established for supply-side resources. This has implications for capturing the capacity value, which are discussed later in this paper. Lampi and Perez [11] discuss different approaches to determine a PV system's installed capacity value. In the case of New York, once an accepted method for determining capacity has been used, the resource can then participate in NYISO's installed capacity markets. The approach utilized here qualifies PV installations as potential demand-side resources. In this case, these resources would be qualified to compete in markets for demand-side resources.

4.2 California PV-Buffer Storage Results

As stated above, the total storage potential for battery-powered EDVs sold in 2003 should be roughly 100 MWhs in the state of California. If we assume that only half of this total energy storage is available to provide buffer storage for PV systems, the battery-powered EV fleet in 2003 could provide firm, peak-shaving opportunities for 63 MW to 50 MW of PV in the state of California.

Furthermore, we calculate the PV capacity that each of the EDVs described above could accommodate given different assumptions with regard to the vehicle owner's driving needs. Figure 2 provides results for the three battery-powered EDVs described in the previous section. The amount of firm PV capacity lies on the vertical axis and the number of driving miles required after proving buffer storage lies on the horizontal axis.

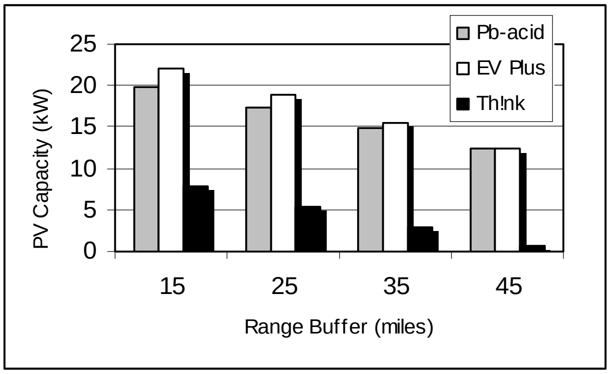

Fig 2. PV Capacity Supported by Vehicle Type in California

According to Figure 2, the lead-acid prototype electric vehicle, assuming a driver-specified range buffer of 25 miles, could provide buffer storage in support of just over 15 kW of installed PV. In the case of SMUD, 1,000 vehicles could provide adequate buffer storage for the 1.5 MW of installed PV within their service territory. Matching EDVs with SMUD's installed PV systems would qualify these resources as demand-side resources.

5. CAPTURING CAPACITY VALUE CREATED THROUGH BUFFER STORAGE

Battery powered EDVs connected to bi-directional grid interconnection points could provide buffer storage to create firm, capacity value for PV installations. The MEBS method, which adheres to standard demand-side management protocols, indicates the storage required in a particular region to achieve firm, peak-shaving equal to the rated capacity of the PV array. There are two interrelated issues that arise from this technical possibility. First, what kind of business model might be adopted to facilitate the use of battery EDVs for buffer storage? Second, how would you determine the value of these demand-side resources? Both of these questions are addressed in the following paragraphs.

5.1 Potential Business Models for EDV Buffer Storage

The scenario proposed here is similar to utility direct load control programs, which have been utilized successfully in many utility service territories across the country. When reserve margins become critically low, the utility company sends a remote signal to cycle off equipment to reduce load. In the case of using EDVs for buffer storage, when the load control was required, the utility would assess the solar resource to determine if the PV resources are available at the level they were given credit for. If the answer is no, then a signal would be sent to parked EDVs to supply power to the grid, again abiding by the vehicle owners range buffer requirements.

A simple business model would consist of an Energy Services company (ESCO) bundling battery-powered EDVs and PV systems into MW blocks for sale in markets for demand-side resources, which are discussed in the next section. There is no technical or economic reason that the EDVs providing buffer storage need to be physically located near the PV systems. There may be some geographical constraints in that a certain percentage of the EDVs must be located in areas where the distributed PV systems are located.

The revenue generated from the sale would be distributed three ways. The ESCO would keep a percentage of the revenue to cover its transaction cost. These costs would include soliciting owners of installed PV systems and owners of EDV with V2G capabilities.

Also, they would incur transaction costs associated with the sale of the demand-side resources. The owner of the EDV must be compensated for making its vehicle available to provide buffer storage. Whatever compensation they receive it needs to be greater than the costs to the vehicle owner associated with battery degradation. Finally, the PV system owner must be compensated for providing the 'virtual' title of the system to the ESCO for the capacity value of the PV installation.

5.2 Valuing PV Capacity Using Buffer Storage

Each regional power market (e.g., CAISO, NYISO, PJM, etc.) incorporates demand-side resources into energy markets differently. The California ISO operates a Participating Load Program (Ancillary Services and Supplemental Energy). This program allows loads to participate as price-responsive demand in ISO Non-Spinning Reserves, Replacement Reserves, and Supplemental Energy markets [12]. Data on market clearing prices in these markets can be found at the California Independent System Operators web site. Accessing and compiling these values is beyond the scope of this current project.
The New York ISO accommodates demand-side resources through their Emergency Demand Response Program. Furthermore, interruptible load resources can qualify to participate in NYIOS's ancillary services and installed capacity markets. Again, historical data on market clearing prices for demand response resources in various markets can be found at the NYISO web site.

A recent study conducted by ICF consulting for the Federal Energy Regulatory Commission (FERC), suggests that markets that accommodate demand-response resources enhance market efficiency [13]. In fact, the final report suggests that efforts to facilitate price-sensitive demand response could be more effective at driving down electricity costs than the FERC regional transmission organization (RTO) initiative. The use of battery-powered EDVs for buffer storage creates a demand-side resource, like those evaluated in the study, which could be used as price-responsive demand/load.

6. CONCLUSIONS

Several states are pursuing policies to promote the use of non- and low-polluting vehicles. Near term guidelines will result in automobile manufacturers selling battery-powered EDVs in several markets. The V2G concept suggests that these and other electric-drive vehicles could provide valuable services to enhance the efficiency and stability of the nation's grid. This paper presents a preliminary analysis of using battery-power EDVs to provide buffer storage for grid-connected PV applications. Expected sales of battery-powered EDVs in California in 2003 would be able to provide buffer storage for tens of MWs of installed PV.

Bundling battery EDVs and PV installations creates firm, peak-shaving resources. As discussed above, we can consider these demand-response resources. Different regions accommodate demand response resources in different ways. Future research should investigate the annual revenues that accrue to demand side resources in different regions. The value of these resources must be judged against the likely costs associated with using battery EDVs to provide buffer storage.

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