BEVs/PHEVs as Dispersed Energy Storage for V2B Uses in the Smart Grid

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***Abstract*—Numerous recent studies have assessed the feasibility of vehicle-to-grid (V2G) mode of discharging, which provides an option to use the energy stored in a battery in electric vehicles to support the power grid. This paper aims at demonstrating the potential benefits of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) as dynamically configurable dispersed energy storage acting in a vehicle-to-building (V2B) operating mode. V2B is a concept that is practically viable today being far simpler than V2G, and it may be implemented on a 3–5 year time horizon while V2G may take 10–15 years to gain wider acceptance. Based on the battery characteristics, the benefits of using BEVs/PHEVs as energy storage for demand side management (DSM) and outage management (OM) are discussed in detail. This paper is also focused on the implementation issues of DSM and OM in the smart distribution grid. A strategy for adopting BEVs/PHEV uses in the V2B mode under the peak load and during outage condition is proposed and demonstrated with test cases and numerical results.**

***Index Terms*—Battery electric vehicle, demand side management, outage management, plug-in hybrid electric vehicle, smart grid, vehicle-to-building, vehicle-to-grid.**

I. INTRODUCTION

POWER SYSTEM security and reliability are becoming more challenging to meet due to the increasing complexity of power system operation. Smart grid deployment has been aggressively pursued with sponsorship and involvement from government, businesses, utilities, and other stakeholders to bring additional knowledge combined with advanced information technology to power grid, which will make the grid more secure and reliable [1]. Currently, utilities in North America are adopting far reaching steps applying the new equipment and advanced technologies trying to meet the emerging requirements of the smart grid. Similar trends may be observed across the world.

With the development of renewable energy coming from such resources as sun and wind, the number of distributed generations increased dramatically. Due to the variability and unpredictability of these renewable energy sources, especially wind energy, high penetration of energy storage systems is highly desirable to make such resources dispatchable. With the distributed generation and energy storage system being connected to the power grid, power network structure becomes more complex. The stressed power system becomes more difficult to control. Maintaining the operational security, reliability and stability while expanding and developing the grid to meet the growing demand remains challenge in future electricity grids.

With the threat of global climate change increasingly acknowledged and the growing concern about energy security, new technologies that will reduce the CO_2 emissions and current dependency on carbon-based fuels have been investigating for some years. The interest in battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) has increased due to their impact on redistribution of the pollution from tail pipe to smog stuck, low-cost charging, and reduced petroleum usages. Compared with traditional hybrid electric vehicles (HEVs), BEVs/PHEVs have an enlarged battery pack and an intelligent converter. Using a plug, BEVs/PHEVs can charge the battery using electricity from an electric power grid, also referred to as "grid-to-vehicle" (G2V) operation, or discharge it to an electric power grid during the parking hours, also referred to as "vehicle-to-grid" (V2G) operation.

Many researchers have investigated the various potential benefits and implementation issues of V2G [2]–[10] concept. Kempton and Tomić studied the fundamentals of using BEVs/PHEVs for load leveling, regulation, reserve, and other purposes [2], [3]. Hadley and Tsvetkova analyzed the potential impacts of BEVs/PHEVs on electricity demand, supply, generation, infrastructure, prices, and associated emission levels in 2020 and 2030 in 13 regions specified by the North American Electric Reliability Corporation (NERC) [4]. Meliopoulos *et al.* considered the impacts of BEVs/PHEVs on electric power network components [5]. Han *et al.* proposed the optimal V2G aggregator for frequency regulation by applying the dynamic programming algorithm to compute the optimal charging control for each vehicle [6]. Shimizu *et al.* [7] and Ota *et al.* [8] also discussed power system frequency control by using V2G system. Anderson, *et al.* performed the case studies of plug-in hybrid electric vehicles if used by regulating power providers in Sweden and Germany [9]. Pillai and Bak-Jensen modeled the aggregated BEV-based battery storage for the use in long-term dynamic power system simulation when integrating V2G in the western Danish power system [10].

However, recent research on the feasibility of V2G is based on the assumption of large-scale penetration of BEVs/PHEVs, which is envisioned on a 10–15 year time horizon in the most optimistic scenarios. As a more near-term application of V2G, vehicle-to-building (V2B) operation is proposed in this paper,

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which is defined as the option of exporting electrical power from a vehicle battery into a building connected to the distribution system to support loads. Due to early adopters, the availability of electrical vehicles (EVs) in major cities may create a critical mass of vehicles for aggregated use to be available 3–5 years from now. With the introduction of smart garage [11], which represents an interface between the transportation network and electric power system, the vehicle charging/discharging infrastructure and control system can be available widely making the proposed V2B idea viable and economically attractive.

In this paper, the potential benefits of BEVs/PHEVs as dynamically configurable dispersed energy storage will be discussed. This includes benefits obtained for the demand side management (DSM) and outage management (OM) improvements from the V2B mode of operation. The applications are focused on using BEVs/PHEVs as storage of electrical energy, which can be utilized in two modes: G2V and V2B. The G2V mode is used to charge PHEVs/BEVs at reduced cost when the power system load is reduced and generation capacity is abundant, such as during night time. The V2B mode is used when demand is high or supply is accidentally lost since the stored electric energy can be released from PHEVs/BEVs in an aggregated way. In this paper, we are not discussing the detailed operation and power drive control models of BEVs/PHEVs. For the purpose of our study the vehicles batteries are simplified to the real power model, and for the V2B applications only.

This paper is organized as follows: Section II discusses the marketplace penetration of BEVs/PHEVs and properties of their charging infrastructures. Section III introduces the benefits of using BEVs/PHEVs in the V2B interfacing mode Section IV discusses V2B implementation considerations. Section V presents the test cases and results. Conclusions of this paper are given in Section VI.

II. PENETRATION OF BEVS/PHEVS

With the increasing price of fuel cost and sustainability consideration, BEVs and PHEVs will become the economical choice for transportation. Widespread adoption of BEVs/PHEVs will improve air quality and decrease the carbon footprint. In this section, the marketplace penetration of BEVs/PHEVs and their charging infrastructures will be discussed.

A. The Marketplace Penetration of BEVs/PHEVs

The penetration rate of BEVs/PHEVs has a drastic impact on the smart grid, which is expected to continuously increase after their wide spread market introduction is made in 2011 and beyond. Multiple studies use either statistical or predictive models to determine the penetration of BEVs/PHEVs. Hadley and Tsvetkova [4] estimate that by 2030 the market share of BEVs/PHEV could reach 25%. Sullivan, Salmeen, and Simon have researched the BEV/PHEV marketplace penetration by the agent based simulation and estimated that the market share in optimistic scenarios could reach around 20% by 2040 [12]. NYISO published a technique report for the potential impacts of PHEVs on New York State's electricity system. They assumed 25% of the fleet will be PHEV by 2030 [13].

TABLE I
ELECTRICAL RATINGS OF DIFFERENT CHARGING METHODS IN NORTH AMERICA

Charging Method	***Nominal Supply Voltage***	***Maximum Current***	***Typical Charge Time***
AC Level 1	120 V, 1-phase	12 A or 16 A	5-8 hours
AC Level 2	208 to 240 V, 1-phase	Up to 80 A	1-2 hours
AC Level 3	208 to 600 V, 3-phase	400 A	10-15 mins.
DC Charging	Up to 600 V	400 A	10-15 mins.

While all these projections are showing large penetration of BEVs/PHEVs not to occur before 20–30 years from now, gas price, tax rebates, electric vehicle subsidies, and sales tax exemptions may accelerate the adoption and create a significant impact on BEVs/PHEVs penetration levels. It is assumed in this paper that a focused availability of such vehicles in major cities due to early adopters will create a critical mass of vehicles for aggregated use to be available 3–5 years from now. In those major cities, the penetration rate should be higher than other areas. If we assumed the penetration rate is double that of the research results by Sullivan *et al.* [12], which could reach 4%–6% with the fleet penetration of around 2%.

B. BEVs/PHEVs Charging Infrastructure

It is assumed that the primary electric vehicle charging station is located at the residence, business, or fleet facility where the vehicle is parked. Also, it is assumed that there are also a number of public charging sites that are available. In North America, standards for installation, including functional and safety requirements of electric vehicle charging infrastructure are provided in the National Electrical Code (NEC) Article 625 [14] and by the Society for Automotive Engineers (SAE) J1772 [15]. SAE J1772 defines the electrical rating of charging methods for conductive charger coupler. Based on the available charging infrastructures, BEVs/PHEVs may be commonly charged by either Level 1 or Level 2 charging method.

Table I shows the detailed information about the different charging methods specified in North American [14], [15]. The Level 1 method uses a standard 120-VAC, 15-amp (12 amp usable) or 20-amp (16 amp usable) branch circuit that is the lowest common voltage level found in both residential and commercial buildings in the United States. Level 1 charging only provides a small amount of power (maximum of up to 1.44 kW), and results in prolonged charging time. The Level 2 method uses a 208 to 240-VAC, single-phase, up to 80-amp branch circuit. Since the typical charging time for a 10 kWh battery pack will be 1 to 2 h, it is the primary and preferred method for the battery electric vehicle charger for both private and public facilities. The faster charging methods are still under development. No standard for the faster charging or connector exists today. Table I shows two typical cases used for faster charging.

For smart garage with charging and discharging abilities, Level 1 and 2 will be ideal choices, since level 3 charging station will increase the power flow capacity requirement dramatically.

TABLE II
DSM BENEFITS TO CUSTOMER, UTILITY, AND SOCIETY [21]

Customer benefits	***Societal benefits***	***Utility benefits***
Satisfy electricity demands	Reduce environmental degradation	Lower cost of service
Reduce / stabilize costs	Conserve resources	Improved operating efficiency,
Improve value of service	Protect global environment	Flexibility of operation
Maintain/improve lifestyle and	Maximize customer welfare	Reduce capital needs

III. BENEFITS OF USING BEVS/PHEVS IN A POWER SYSTEM

Most of the time vehicles sit idle parked at homes, streets, parking lots, or garages; hence BEVs/PHEVs battery capacity can be fully utilized during such times. Therefore, BEVs/PHEVs could serve as decentralized energy storage in a smart grid and can act as either a load or a generator as needed. Certainly, the value of this function must be balanced with the inefficiency and battery-life impacts of reverse power flow. It has negative effects on battery life, but advanced battery technology is good enough to support the lifetime of most available BEV/PHEV vehicles [16], [17]. BEVs/PHEVs may be an attractive integral part of a smart grid, when aggregated in sizeable numbers and capable to operate in the V2G mode.

V2B is defined as exporting electrical power from a vehicle battery into a building. It considers batteries in BEVs/PHEVs as a generation resource for the buildings via bidirectional power transfer through energy exchange stations (chargers/dischargers) at certain periods of time, which could increase the flexibility of the electrical distribution system operation. It is expected that V2B operation will improve the reliability of the distribution system, provide extra economic benefits to the vehicle owners, and reduce the home or building electricity purchase cost based on the demand side management (DSM) and outage management (OM) programs with customer incentives [18].

A. Demand Side Management (DSM)

For electric utility, DSM is defined as “the planning, implementation, and monitoring of distribution network utility activities designed to influence customer use of electricity in ways that will produce desired changes in the load shape,” which includes peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape [19]. However, for utility end-user (customer), DSM is often understood to include two components: energy efficiency (EE) and demand response (DR). EE is designed to reduce electricity consumption during all hours of the year; DR is designed to change on-site demand for energy in intervals and associated timing of electric demand by transmitting changes in prices, load control signals or other incentives to end-users to reflect existing production and delivery costs [20]. The utility and customer cooperatively participating in DSM will provide the benefits to the customer, utility, and society as a whole, which is summarized in Table II [21].

In the V2B operation, the owners will plug in their vehicles during the day at their final destination for a given time frame. As an example, this may be either at their workplace (central business district) or at the place of their study (university). The destinations, either parking lots or parking garages, are assumed to be equipped with a bidirectional charger and controller. The parking facility should allow either charge or discharge mode for the car batteries when necessary. The idea is that the parking facility can offer an aggregation service for charging the batteries when the demand of V2B supported building is lower than its peak load and discharge the batteries to partially supply the building to reduce the peak demand during a high demand. The objective of DSM is to improve reliability of power supply for the building and create revenue.

Power system utilities in North America offer a variety of load control and demand side load management programs to their clients. These programs can provide enhanced power system security and many benefits to their participants. For example, Southern California Edison (SCE) has introduced a number of demand response programs, such as Demand Bidding Program (DBP), Critical Peak Pricing (CPP) [22]. Considering the electricity rate is lower when the vehicle batteries were charged than when the batteries are discharged, the battery storage may be used to offset high cost during the peak demand. The formulas for calculating revenue depend on the program that the V2B power resource is participated in. In this paper, a typical business customer is considered as demonstration scenario. There are three basic charges for business rate schedule: customer charge, energy charge, and demand charge. Consequently, the monthly total revenue r for BEVs/PHEVs based V2B operation is calculated as

$$r = E_{ec}(r_{\mathrm{rc\_onpeak}} - r_{\mathrm{rc\_midpeak}}) \times t + r_{\mathrm{tdc}}(P_{\max} - P_{\mathrm{dsm\_max}}) \qquad (1)$$

where:

E_{ec}	the energy shifted from on-peak time to midpeak time (kWh);
$r_{\mathrm{rc\_onpeak}}$	the on-peak time energy charge rate ($/kWh);
$r_{\mathrm{rc\_midpeak}}$	the mid-peak time energy charge rate ($/kWh);
t	number of days in a month;
r_{tdc}	the time-related demand charge ($/kW);
$P_{\max}$	the maximum on-peak power demand (kW);
$P_{\mathrm{dsm\_max}}$	the maximum on-peak power demand after demand-side management (kW).

In practical application, for the given electric vehicle, the actual maximum power from V2B is calculated as

$$P_{\mathrm{vehicle}} = P_{\mathrm{ideal}} \times \eta_{\mathrm{charger}} \times \eta_{\mathrm{inv}} \times \eta_{\mathrm{other}} \qquad (2)$$

where:

P_{vehicle}	the actual maximum power for V2B (kW);
P_{ideal}	the ideal maximum power from V2B, usually it is the maximum power of charging station (kW);

η_{charger}	the efficiency of charger;
η_{inv}	the electrical conversion efficiency of the dc to ac inverter;
η_{other}	other factors, such as power loss, battery self-discharge, etc.

As an example, the studied case is presented in Section V with the detailed rate structure of SCE.

B. Outage Management (OM)

Another important benefit of V2B is using the battery energy storage in BEVs/PHEVs as an emergency back-up power for the commercial facility/building, which increases the reliability of the power supply for that load.

An outage is typically caused by several unplanned events and a timely detection and mitigation of such situations is a real concern for the utility. Outage management system helps the operators to locate an outage, repair the damage and restore the service with a minimal interruption of service to the customer. Outage management must be performed very quickly to reduce outage time. Recently completed project proposes an optimal fault location scheme which will help the operator to find the faulted section very quickly [23]. In this paper we will focus mainly on the restoration strategy under an outage for a commercial facility or building.

Outages for a commercial facility or building(s) and studies about the impact of PHEVs/BEVs adoption are considered.

These may be caused by a fault occurring inside the distribution system feeding the buildings and can be mitigated by precise spatial adjustment of energy generation from BEV/PHEV battery that may offer local generation support during and shortly after the outage.

To propose the restoration strategy where BEVs/PHEVs are used to mitigate an outage condition for the buildings being affected, we need to correlate the information about events (where the fault is located and how the impact will propagate) and the location of the energy storage. Thus, a spatial as well as temporal analysis should be performed.

The restoration strategy can be executed in the following steps:

1) Detect a fault.
2) Estimate the location of the fault.
3) Analyze the amount of generation required to support the building and the availability of BEV/PHEV that can provide an alternative generation until the faulted section is repaired. This will also consider the generation connection time requirement (i.e., time to repair the faulted section).
4) Implement V2B by scheduling the aggregated energy generation from BEVs/PHEVs batteries optimally. The technique of V2G converters has been proved to be feasible in PJM [24]. This is a multiobjective optimization problem which can be formulated as: minimize operating cost, real power loss, time of outage under system operation and security constraints. The detailed mathematical formulation of the optimization problem is discussed in Section IV-B. For simplicity we have used cost minimization objective in this paper but the optimization problem can be easily expanded to a multiobjective problem considering all of the objectives.

IV. V2B IMPLEMENTATION CONSIDERATIONS

Smart grid aggressive deployment has begun with sponsorship and involvement from government, businesses, utilities, and other stakeholders. BEVs/PHEVs represent an attractive method of transportation as they have the ability to charge the battery using low-cost, off-peak electricity from the power grid. Being treated as an integral part of the smart grid, BEVs/PHEVs can be considered either as generators or loads, which could be used to affect the electricity market if the penetration becomes significant. The novel power grid could help integrate the stored energy in the BEVs/PHEVs batteries and their controllable charging/discharging capacity. In this section, implementation considerations for V2B are discussed.

A. Vehicle Assumptions

Rechargeable batteries are one of the most important components of the BEVs/PHEVs. Many researchers have conducted several studies on design and requirements, cost-effectiveness assessment, and performance of BEV/PHEV battery, which included the nickel-metal hydride (NiMH) [16] and lithium-ion (li-ion) [17] technologies. The study results have shown that the advanced battery technology is good enough to support the most of the available BEV/PHEV vehicle models. Battery capacity for BEVs/PHEVs depends on the electric range and the vehicle electric drive efficiency. The uncertainty about what the most economical size and configuration of marketable BEVs/PHEVs when comparing the battery pack size, electric motor size, and IC engine size should be is still high.

Denholm *et al.* provided the estimations of the potential miles displaced by electricity for a variety of PHEV ranges [25]. Their results show the range from 0.25 kWh/mile for compact vehicles to 0.42 kWh/mile for large SUVs. Thus, for a compact PHEV-20 (referring to a vehicle that may be driven 20 miles before the state of charge (SOC) hits the acceptable lower limits), 5.0 kWh is required for the usable battery capacity over this range of vehicles. For a large SUV PHEV-40, 14.4 kWh is required. The assumed an average usable battery capacity of 10.2 kWh [25]. The Electric Policy Research Institute (EPRI) reports that 50% of American automobiles travel less than 26 miles/day, which is shown in Fig. 1 [26]. Thus, PHEVs that could operate 26 miles on battery power alone would have the potential to meet half of America's daily automotive transportation needs. Hence PHEV-40 or similar BEV is chosen as the typical electric vehicles in this paper. Two popular electric vehicles are selected for demonstration of V2B operational mode: Chevy Volt and Nissan Leaf. Table III summarizes the fundamental specifications of two vehicles [27], [28]. Particularly, Level 3 chargers may supply very high voltages (for example, 300–500 VDC) at very high currents (over 100 amperes). It is possible that Nissan Leaf can draw 24 kWh in 30 min.

B. BEV/PHEV Integration

A security constrained optimal power flow to schedule energy generation from BEV/PHEV battery was proposed and

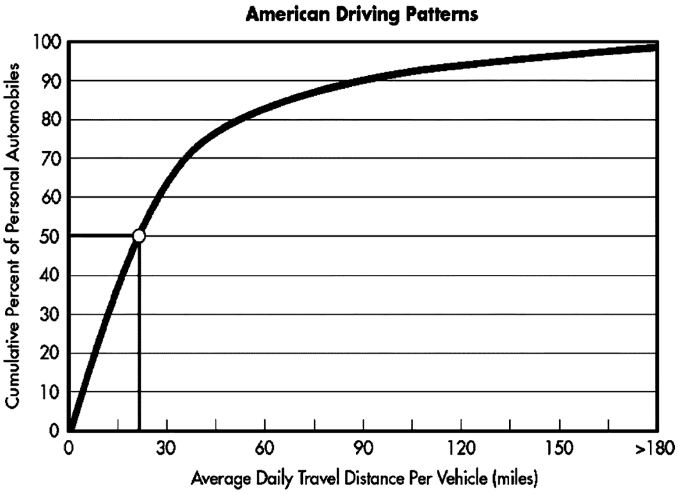

Fig. 1. American daily vehicle travel [26].

TABLE III
ELECTRIC VEHICLES BATTERY SPECIFICATIONS

Auto Model	*Battery Type*	*Capacity (minimum)*	*Range*	*Charging Time*
Chevy Volt	Lithium Ion	16 kWh	40 miles	6-6.5 hours (240V)
Nissan Leaf	Lithium Ion	24 kWh	73 miles	7 hours (240V) 30 minutes (quick charger)

tested using an IEEE test systems before [4], which tries to minimize the operating cost under normal system operation. In this section we will discuss a restoration strategy by scheduling BEVs/PHEVs optimally under outage condition. This will basically provide a generation support (by using BEVs/PHEVs) to a building experiencing power outage.

The restoration strategy based on scheduling BEVs/PHEVs by optimizing a multiple-objective problem is proposed here. The problem can be stated as

$$\begin{aligned} \text{Min} \quad & f_i(\underline{x}, \underline{u}, \underline{p}) \\ \text{s.t} \quad & g_i(\underline{x}, \underline{u}, \underline{p}) = 0 \quad i = 1, 2, \ldots, m \\ & h_i(\underline{x}, \underline{u}, \underline{p}) \leq 0 \quad i = 1, 2, \ldots, n \end{aligned} \tag{3}$$

where:

$f_i(\underline{x}, \underline{u}, \underline{p})$	the functions to be minimized;
$\underline{x}$	the vector of state variables;
$\underline{u}$	the vector of control variables (location and amount of BEV/PHEV batter generation);
$\underline{p}$	the vector of fixed parameters;
$\underline{g}$	equality constraints;
$\underline{h}$	inequality constraints.

The objective functions can be cost minimization, real power loss minimization, minimization of time of outage (depending on the discharge rate of the chosen vehicles). Cost minimization is the traditional economic load dispatch approach, which is done for minimizing generation cost (BEVs/PHEVs here) while maintaining set of equality and inequality constraints. Loss minimization is typically performed by minimizing total transmission loss of the system. This is done by controlling voltages of the generating units while keeping controllable generator real power outputs constant except for changing output of one generating unit only (called slack bus or swing bus). Thus, when the loss is minimized the slack bus generation is also decreased as this is dependent upon the total loss. Thus, the total cost is further decreased after the loss minimization. Though outage time is dependent on several other factors (time to locate fault, time to repair etc.), the effective outage time (i.e., from time of fault to start of backup by vehicles) can be reduced by having more vehicles in the vicinity and choosing vehicles having lesser time to discharge.

Presently due to lack of available data, we are considering only the cost minimization objective. The objective function can be formulated as

$$f(\underline{x}, \underline{u}, \underline{p}) = \sum_{i=1}^{N_G} \beta_G[i] \cdot P_G[i] \tag{4}$$

where:

$P_G[i]$	active power generation of ith BEV/PHEV battery;
$\beta_G[i]$	cost coefficient of ith BEV/PHEV battery generation: depends on the type of vehicle as well as type of parking garages.

The equality constraints are the power flow equations. The inequality constraints are the BEV/PHEV battery generation limits, bus voltage limits, and line overload limits.

The restoration strategy is executed using the following procedure. A fault location scheme detects and locates the fault. Depending on the location of the fault, an analysis is performed to determine amount of load affected and location of Smart Garage near the buildings being affected. Now, depending on the availability and state of charge of the aggregated vehicles and the maximum generation and price of discharging aggregated batteries in garages, total cost will be minimized. While this procedure is a spatial analysis, a temporal analysis which will take care of the discharge rate and availability of vehicles, as well as the time to repair the fault will also be performed.

C. Data Requirements

Data availability is an important factor for the implementation. Different types of data from various sources are needed to implement the proposed algorithms. The typical data are summarized as below:

- power system static data;
- real time topology information & load data;
- event data;
- location of the fault;
- location of the building which is out of electricity due to the fault;
- possible location of PHEV/EBV battery generation;
- availability and possible amount of generation (that will depend on the number of vehicles, state of charge, and owner's choice);

- status and performances of charging stations;
- price of charge/discharge;
- time to charge/discharge.

V. CASE STUDY FOR USING BEVs/PHEVs IN V2B

Test cases for two scenarios are studied: demand side management using V2B mode during peak power demand and outage management using V2B mode during faults.

A. Demand Side Management During Peak Power Demand

In this case, a large commercial building is analyzed to demonstrate the potential savings using demand side management based on V2B operation. Iron, Inc. prepared a technical survey for the California Energy Commission (CEC), which modeled different commercial sectors, including large office building [29]. The load shapes include typical day, hot day, cold day, and weekend for each of four seasons. According to the definition used in this report, large office buildings are defined as premises with total floor area equal or larger than 30 000 square feet. The largest electric end-uses in this building type are interior lighting, cooling, office equipment, and ventilation [29].

The summer typical load shape for a large office building is selected for our case study. The single building demand is obtained from the results reported in the literature [29]. The following assumptions are taken:

- the studied building is 450 000 sq ft;
- there are up to 80 BEVs/PHEVs that arrive at 8 A.M. and are available for the entire day;
- maximum capacity of each vehicle is 15 kWh;
- the batteries in BEVs/PHEVs are drained on average by 4.0 kWh one way during the driving cycle used;
- the charging levels assumed are ac Level 2: 208–240 VAC

The 450 000 sq ft building is the typical size of commercial building in metropolitan area. The typical garage will have the ability to provide the charging service for hundreds of vehicles. Thus, availability of 80 electric vehicles is a reasonable assumption. All the BEVs/PHEVs owners will charge their vehicles till full during the night at lower rate. Level 2 charging is ideal for commercial use at lower cost with good performance.

When BEVs/PHEVs are on site, the building can charge the batteries during the morning hours (lower electricity price) and drain the batteries during afternoon hours (higher electricity price). Certainly, the necessary amount of battery energy will be assured to let the owner of BEV/PHEV have sufficient SOC in their battery storage to meet the driving cycle on return home. This lower boundary is set as 6.0 kWh considering the charging/discharging SOC patterns. With the available ac Level 2 charging stations, BEV/PHEV batteries can be charged to full capacity in less than 1 h. Faster charging stations (ac Level 3 or dc charging) can finish the charging process in 30 min. Fig. 2 shows the impacts of charging BEVs/PHEVs by ac Level 2 (4 kW power level) charging stations. The load demand profiles of the building with and without BEVs/PHEVs load are presented in this figure. From Fig. 2, charging electric vehicles will elevate the peak demand of the office building to 1.94 MW since the charging method causes a large load in a short period. This is not recommended for either utilities or customers.

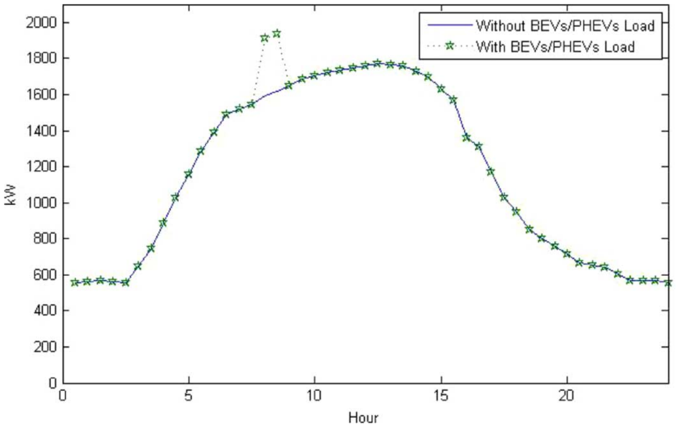

Fig. 2. Impacts of faster charging BEV/PHEVs on load demand.

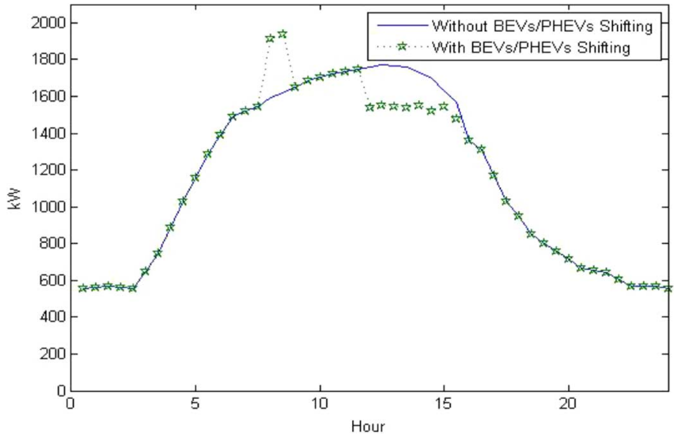

Fig. 3. Peak load shifting with BEVs/PHEVs for a typical summer daily load.

Fig. 3 shows the change in the load shape for the typical summer day by using BEVs/PHEVs based V2B operation mode. The load curve is changed by shifting the afternoon peak load to the morning off-peak load when charging and discharging the BEVs/PHEVs. The electric vehicle discharging covers a larger area than the charging. The extra energy is coming from night time charging at home with reduced cost.

B. Monthly Revenue of V2B Based DSM

Considering the rate structures for peak and off-peak load in commercial buildings, peak load shifting using V2B mode may provide the electricity bill saving. Let us use the example of Southern California Edison (SCE) utility company. For business rate plans, SCE provides the plan of Time-of-Use-General Service-Large (TOU-8), which is a flexible, customized rate schedule to help SCE and its business customer save money [22].

For most business customers, utility will customize their rate schedule by using four day types—weekday, weekend, hot day (weekday), cold day (weekday), and for four seasons (winter, spring, summer, fall). In our case, TOU-8 energy rates are divided into three time-of-use periods: on-peak, mid-peak, and off-peak. In summer season (June 1 to October 1), mid-peak time is defined as 8 A.M.—noon weekdays except holidays; on-peak time is defined as noon–6 A.M. weekdays except

TABLE IV
SEC RATE SCHEDULE FOR TOU-8 PRIMARY VOLTAGE (SUMMER SEASON) [22]

Customer Charger	***Demand Charge (per kW)***	***Energy Charge (per kWh)***
$275.69 Per month per meter	Facilities-related: $10.18 per monthly maximum kW per meter	On-peak: $0.11086 Mid-peak: $0.09096 Off-peak: $0.06483
	Time-related: $15.48 per maximum On-peak kW in the summer season only	

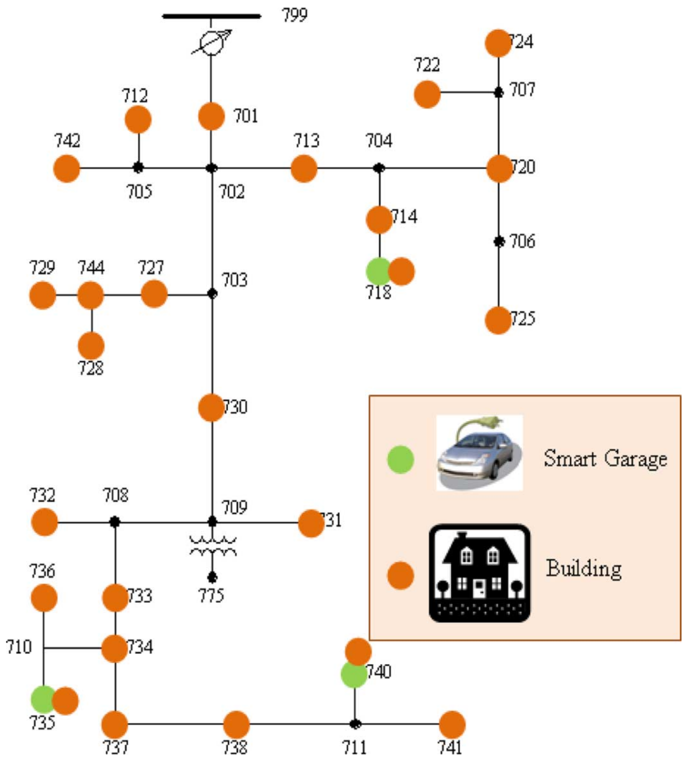

Fig. 4. Diagram of test feeder with smart garages.

holidays. The rest are off-peak times. Table IV summarizes the SCE rate schedule of TOU-8 Primary Voltage (from 2 kV to 50 kV) in the summer season [22].

In the example of peak load shifting with BEVs/PHEVs, 720-kWh power demand will be shifted from on-peak to mid-peak. At the same time, with the shifting load, the maximum on-peak energy demand reduces from 1.7743 MW to 1.5493 MW. Hence, according to (1), the ideal monthly revenue (20 weekdays) for V2B based DSM operation will be $3769.56 (Appendix). By considering the charging efficiency, the conversion efficiency, power loss, battery self-discharge, etc. the monthly revenue will be deduced to $2839.61 (Appendix). We do not consider the battery capital cost. Since each battery will be only charged and discharged once as its regular routine, the charging cycles for these batteries do not increase.

C. Outage Management

The proposed restoration scheme was tested on a small distribution system (IEEE 37 node radial test feeder [30]). Fig. 4 shows the test feeder with smart garages at some nodes (marked as green circles) and buildings in several nodes (marked as orange circles).

This is an actual feeder located in California, which consists of several unbalanced spot loads (we considered the spot loads as buildings here). The nominal voltage is 4.8 kV. The hourly load distribution data throughout the year as a percentage of peak load (product of weekly peak, daily peak, and hourly peak) is obtained from literature [31]. We have considered a winter morning (Thursday of 40th week at 11 A.M.) and a summer morning (Thursday of 20th week at 11 A.M.) and considered outage time of 30 min.

The following assumptions are taken:

- Three nodes are specified as smart garages (nodes 718, 735, and 740).
- The total number of cars in garage at node 718 is 65, at node 735 is 55, and node 740 is 70.
- Maximum capacity of each vehicle is 15 kWh (10 kWh is available to use for OM).
- Discharge vehicles with state of charge (soc) >70%.
- BEV/PHEV tariff for charging is 5 c/kWh and for discharging is (15–40) c/kWh (depending on different garages). Discharging tariff for node 718 is 40 c/kWh, for node 735 is 30 c/kWh, for node 740 is 25 c/kWh.

Under normal operating condition, node no. 799 acts as an infinite bus and all the loads are fed through it. We have studied two different outage cases:

1) Case 1: Fault on or beyond node 799: In this case, there is no external generator supply in the distribution system we considered (shown in blue part of Fig. 5 i.e., the entire distribution system except node 799). Battery generation of BEVs/PHEVs at nodes 718, 735, and 740 were scheduled to support all the buildings on the feeder. Table V shows the case results.
2) Case 2: Fault on line segment 703–730: In this case, part of the distributed system is supplied by external sources (Node 799 will support all the buildings between node 799 and the line segment 703–730) and the segment after node 730 has no external supply and therefore should be backed up by battery generation (shown in pink part of Fig. 5). Battery generation of BEVs/PHEVs at nodes735 and 740 will be scheduled to satisfy the island created by a fault on line 703–730. Table VI shows the case results.

VI. CONCLUSION

Based on the battery charging/discharging characteristics of electric vehicles, the G2V and V2B scenarios are studied. This paper discusses the potential benefits of using BEVs/PHEVs as dynamically configurable dispersed energy storage that can serve as load or generation in a power system as needed. It is concluded that BEVs/PHEVs could play a major role in the distribution grid by serving in G2V as well as V2B mode if aggregated. Based on the discussions presented in this paper that focuses on V2B operation, the following conclusions can be drawn.

- The use of BEVs/PHEVs battery as dispersed energy storage should meet requirements for the charging/discharging infrastructure leading to the practical data necessary for V2B operation.

TABLE V
CASE STUDY 1: RESULTS FOR BEV/PHEV BATTERY GENERATION SCHEDULING

Date & Time	***Node 718***			***Node 735***			***Node 740***			***Cost of scheduling ($)***
	Ph-1 (kW)	Ph-2 (kW)	Ph-3 (kW)	Ph-1 (kW)	Ph-2 (kW)	Ph-3 (kW)	Ph-1 (kW)	Ph-2 (kW)	Ph-3 (kW)	
Thursday of 40th week at 11 a.m.	0	0	68	320	320	320	165	106	340	450.6
Thursday of 20th week at 11 a.m.	0	0	224	320	320	300	269	198	340	572.2

TABLE VI
CASE STUDY 2: RESULTS FOR BEV/PHEV GENERATION SCHEDULING

Date & Time	***Node 735***			***Node 740***			***Cost of scheduling ($)***
	Ph-1 (kW)	Ph-2 (kW)	Ph-3 (kW)	Ph-1 (kW)	Ph-2 (kW)	Ph-3 (kW)	
Thursday of 40th week at 11 a.m.	234	85	254	0	0	0	143.2
Thursday of 20th week at 11 a.m.	284	103	309	0	0	0	174.1

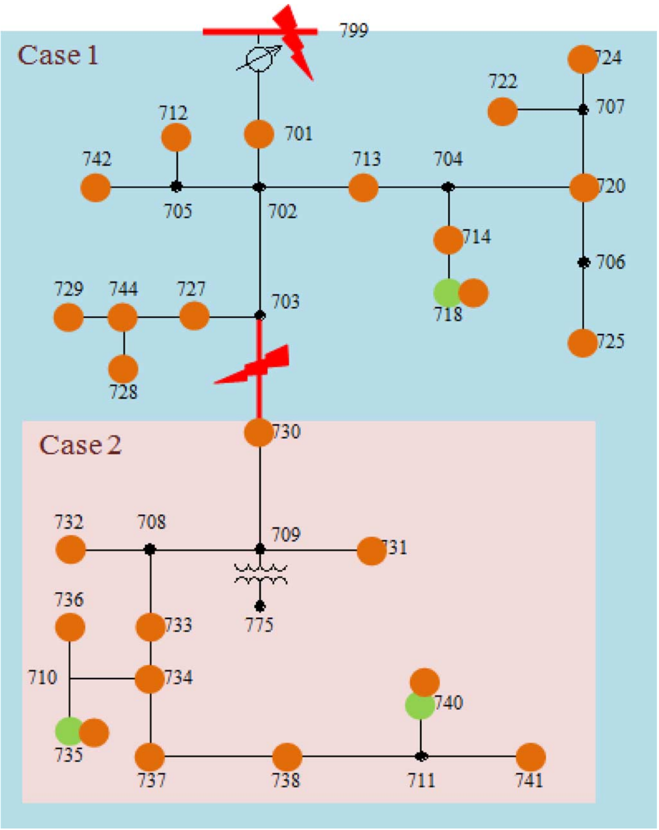

Fig. 5. Different outage cases.

- For demand side management, the peak load shifting strategy using BEVs/PHEVs can reduce on-peak load demand and energy consumption, which in turn will reduce the electricity purchase cost for the customer and vehicle owner.
- For outage management, the outage restoration for buildings using BEVs/PHEVs to generate power during faults in the main grid is envisioned by solving a optimization problem of merit-order scheduling of BEV/PHEVs under operating constraints.
- Case studies demonstrate the feasibility of the proposed demand side management and outage management strategies, which suggest that with enough available BEVs/PHEVs, the aggregated batteries could be used to support the electricity demand of a typical building and create revenue for vehicle owners.

TABLE VII
IDEAL REVENUE FROM ELECTRIC VEHICLES BASED DSM

Revenue Parameters	***Values***	***Comments***
E_{ec} (kWh)	720	Assume: 80 EVs with 9 kWh available energy to use for each battery (15 kWh-capacity battery with 6.0 kWh reserved considering SOC pattern)
r_{rc_onpeak} ($/kWh)	0.11086	On-peak energy charge rate in SCE TOU-8 in summer season
$r_{rc\_midpeak}$ ($/kWh)	0.09096	Mid-peak energy charge rate in SCE TOU-8 in summer season
t (day)	20	Assume: 20 workdays per month
r_{tdc} ($/kW)	15.48	Time-related demand charge for maximum on-peak power in SCE TOU-8 in summer season
$P_{\max}$ (kW)	1774.3	The maximum on-peak power demand of the study building
$P_{dsm\_\max}$ (kW)	1549.3	The maximum on-peak power demand after DSM

APPENDIX

The monthly revenue of V2B based DSM operation described in Section V is calculated. The monthly revenue depends on the amount of V2B energy shifted from mid-peak time to on-peak time, and the incentives provided by the demand side load management program of local utilities. In this paper, Southern California Edison (SCE) pricing situation is considered as the case study. The monthly revenue is calculated according to (1). It is assumed all the shifted energy from on-peak time will be charged in mid-peak time. Certainly, it will bring more revenue if the shifted energy is charged in off-peak time. Table VII shows the calculation of the ideal revenue from electrical vehicles participating in DSM program.

The total monthly revenue of DSM in this case will be

$$\begin{aligned} r &= E_{ec}(r_{\mathrm{rc\_onpeak}} - r_{\mathrm{rc\_midpeak}}) \times t \\ &\quad + r_{\mathrm{tdc}}(P_{\max} - P_{\mathrm{dsm\_max}}) \\ &= 3769.56(\$) \end{aligned}$$

The actual revenue will be reduced with considering the charging efficiency, the conversion efficiency, power loss, battery self-discharge, etc. Assume the efficiency of charger $\eta_{\mathrm{charger}} = 0.9$, the conversion efficiency $\eta_{\mathrm{inv}} = 0.93$, and $\eta_{\mathrm{other}} = 0.9$, the actual revenue will be

$$r_{\mathrm{actual}} = \eta_{\mathrm{charger}}\eta_{\mathrm{inv}}\eta_{\mathrm{other}} \times r = 2839.61(\$)$$

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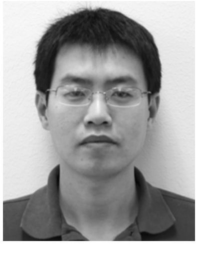

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