INHERENT POTENTIAL OF ELECTRICAL VEHICLES TO FLATTEN THE DAILY LOAD CURVE IN A MICROGRID

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ABSTRACT

Microgrids are the building blocks of future electric distribution systems and electrical vehicles (EVs) are the future of transportation market. In this paper, the impact of EVs on the performance of microgrids is investigated. Demand side participation as a good countermeasure is used to cope with the increasing demand for charging. Vehicle-to-grid (V2G) functionality is well suited in this regard. Therefore, a market-clearing mechanism based on charging/discharging of EVs and demand response is formulated that accepts bids from the demand and supply sides, meanwhile taking into account the constraints put forward by different parties. Two optimization problems are designed: one for a day-ahead market with the bids and offers whose objective is maximizing the difference between the cost of producing/purchasing demand and the offered price by consumers plus the benefit of the EV owners participating in the V2G functionality and the other one by minimizing the square root of the sum of the differences between the demand and the average daily load in order to fill the gap between the peak and valley.

INTRODUCTION

Connection of distributed generation resources (DERs) near the energy consumers in low/medium voltage distribution systems is applicable by the microgrid's concept. Hence, a microgrid could be a combination of DERs, storage devices and controllable loads operating autonomously or in utility-grid connected mode in a controlled and coordinated way [1]. Therefore, it is expected that in near future, on one hand, the distribution utilities will be directed towards implementing the concept of microgrid in their systems; this is also confirmed in IEEE standard 1547.4 stating that the microgrid structure is the building block of future distribution systems [2]. On the other, e-mobility is the future of transportation, so it is foreseen that significant amount of EVs would be penetrated in the structure of microgrids due to the future rapidly increasing low emission transportation market [3]-[4].

Although the increasing penetration of electric vehicles (EVs) has a lot of significant environmental advantages, it could remarkably affect the load demand by its rapid growth. The load demand requested by EVs has serious differences with the traditional ones from the viewpoint of uncertainty, randomness and disparity. So this demand has complicated effects on the energy management and economic dispatch of the distribution system especially if the aspect of uncontrollability is taking into account. Fortunately, a good opportunity is expected by the microgrid concept in meeting the challenge of increasing load demand created by a large number of EV loads; as a microgrid has enough flexibility to interact with the EVs due to its high penetration levels of DERs. EVs with V2G functionality are able to operate as supply/demand based on the request by the control system, thereby assisting in dealing with the generation shortage by appearing as fast-response units [5].

It is indicated in [6] that the microgrids could accept more DERs by the participation of EVs in their ancillary services, meanwhile, appropriate utilization of standby batteries of EVs for power regulation in conjunction with the traditional interruptible loads is a difficult task; hence, a solution for islanded operation is provided by evaluating the battery level of EVs in the pricing mechanism and instructing the aggregated dispatch in terms of operative costs and system deviations by price signals.

In [7] a stochastic energy scheduling with intermittent DERs is proposed to minimize the expected operational cost of a microgrid while reducing power losses by optimally scheduling the EVs' charging loads and DERs. In [8] charging of EVs is considered as interruptible load and discharging them as emergency units to improve system well-being. It is shown that the charging/discharging limits and the EV population are more effective on reducing the daily risk by V2G than on the energy capacity of EV. The procedure proposed in [7] shows that the capacity for interruptible load and V2G can be used in studies where flexible EV charging is allowed.

The problem of allocating energy from renewable sources to EVs in a cost efficient manner is analyzed in [9]. The intermittent nature of renewable energy supply and the necessity of satisfying the EVs' charging requests within a specified time frame, even by additional cost of drawing surplus energy from the power grid are taken into account. A stochastic optimization problem based on queuing model to minimize the time average cost of using non-renewable energy sources is formulated by the Lyapunov optimization technique to solve the problem. EVs are considered as controllable loads or distributed energy storage units, which can further benefit the grid system with demand response or load following. It is worth noting that the proposed optimization approach based on Lyapunov technique is compared with two other EV control strategies: "charge-upon-arrival", which charges EV with all available power as soon as the EV is connected to the grid and "purchase-at-deadline", which charges EV with renewable energy only except when the deadline approaches.

In [10] a strategy for grid power peak shaving and valley

filling using V2G based on an objective function of V2G peak-shaving control is proposed and the main constraints are formulated. The effectiveness of peak shaving using V2G is shown by simulations.
In this paper DERs, demand side bidding (DSB) including demand response (DR), optimized EVs charging and V2G availability are considered as controllable segments in the operation of the microgrid. The main objective is the economic operation of a sample microgrid based on DSB and controlled/uncontrolled charging of EVs under various operating conditions. Followings are the main points that are investigated in this study:

- Different scenarios and different market tariffs are considered when analyzing the impact of customers' behavior on the operation of the microgrid.
- Each individual vehicle in the system is treated independently as the EVs charging behavior such as residence time, arrival rate, and driver preferences is random and there is still a lack of sufficient historical data to accurately model the EVs charging behavior.
- An efficient stochastic model for charging of different EVs in weekdays and weekends based on the expected service from each EV is extracted, taking into account the battery characteristics, charging behavior, and charger ratings of each individual vehicle.
- EV is considered as an electric shifting demand, peak clipping, and a source of energy during inadequate generation in unscheduled events, thereby, coordinated operation and control of microgrid resources with proper integration of EVs' charging/discharging coordination schemes is utilized.
- The mixed integer non-linear programming optimization problem is decomposed into one master problem for energy scheduling and one subproblem for power flow computation. The two problems are solved iteratively by interfacing MATLAB with GAMS.
- A sample microgrid with different residential, commercial and industrial consumers with associated demand side biddings and different penetration level of EVs are simulated to validate the proposed formulation of the problem and the applied methods.

MODELING THE ELECTRIC VEHICLES

Simulation of the impact of V2Gs on the microgrid operation needs determining the probability of availability of EVs at the parking lot. Different EV owners such as residential, commercial and industrial consumers need to be considered. Therefore, the statistics of their travelling habits and travelling loads are used to extract the probabilities of their availability in the parking lot [11]-[12]. Figures 1 to 4 show the probability of the availability of the EVs at parking lots prepared by extending the data and figures presented in [11]. Figure 1 shows the probability of presence of the EVs in a residential parking lot for weekdays and also weekends. Figure 2 shows the same but for a commercial EV.

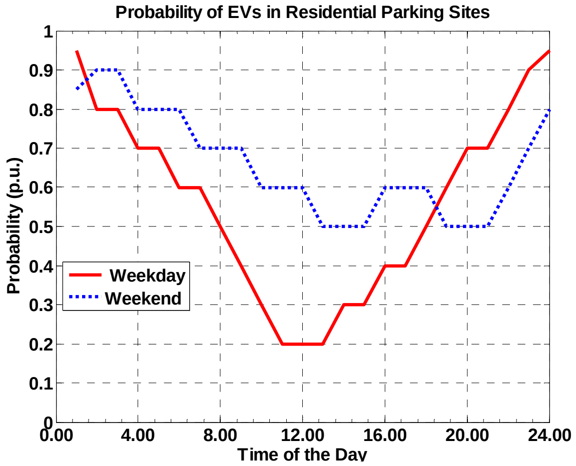

Figure 1: The probability of availability of an EV in a residential parking lot for weekdays and weekends.

As can be deduced from this figure, the probability of availability is relatively in contrast to the residential ones, as the staff are not mainly use their EVs in the daytime.

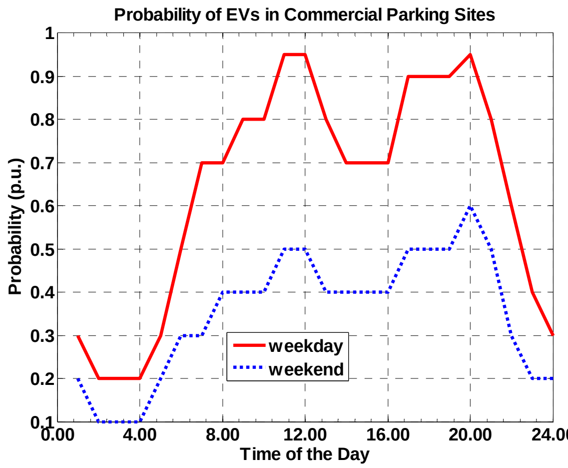

Figure 2: The probability of availability of an EV in a commercial parking lot for weekdays and weekends.

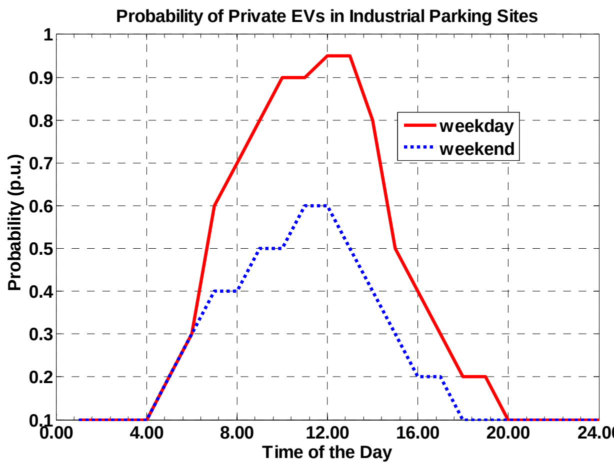

Figure 3: The probability of availability of a private EV in an industrial parking lot for weekdays and weekends.

Figure 3 and 4 show the probability of the availability of the EVs for industrial parking lots. According to these figures, there is a distinction between private EVs and industrial EVs, as the industrial ones are normally of the parking lot for performing their duties, while the private EVs are usually available at the parking lot of that industry.

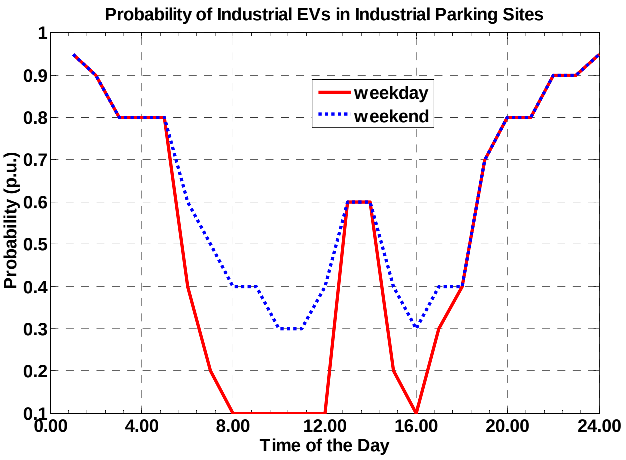

Figure 4: The probability of availability of an industrial EV in an industrial parking lot for weekdays and weekends.

In the modeling, three binary values are used for indicating the status of EVs at the parking lots for representing their charging, discharging and idle statuses. The sum of these binary variables is equal to another binary parameter that indicates the presence or absence of EVs at the parking lot. A parameter is derived from the probability of availability of EVs at the parking sites according to Figure 1.

$$u_{ch}^{v,t} + u_{dch}^{v,t} + u_{idle}^{v,t} = A^{v,t} \quad (1)$$

$$E_{ch}^{v,t} = \frac{I_{batt} \cdot E_{\max}^{v} \cdot u_{ch}^{v,t}}{C_{batt}^{v} \cdot \eta_{ch}^{v}} \quad (2)$$

$$E_{dch}^{v,t} = \frac{I_{batt} \cdot E_{\max}^{v} \cdot u_{dch}^{v,t} \cdot \eta_{dch}^{v}}{C_{batt}^{v}} \quad (3)$$

Equations (2) and (3) show the charged or discharged electric energy of each vehicle at period *t,* respectively. The objective function is the difference between the consumer gross surplus and the total EVs' benefit minus the operation cost, which are all calculated at the time interval *t*. The total vehicles benefit at each period can be defined as:

$$VB^{t} = \sum_{v=1}^{V} \left(\left(E_{dch}^{v,t} - E_{ch}^{v,t} \right) . \lambda^{t} \right) \quad (4)$$

where

$u_{ch}^{v,t}$ Binary variable that is equal to 1 if EV number *v* is in charge state at period *t*

$u_{dch}^{v,t}$ Binary variable that is equal to 1 if EV number *v* is in discharge state at period *t*

$u_{idle}^{v,t}$ Binary variable that is equal to 1 if EV number *v* is in idle state at period *t*

$SOC^{v,t}$ State of charge of EV number *v* at period *t*

$E_{ch}^{v,t}$ Energy charged by EV number *v* at period *t*

$E_{dch}^{v,t}$ Energy discharged by EV number *v* at period *t*

VB^{t} Vehicles' benefit at period *t*

If filling the gap between valley and peak is desired, then the objective function could be minimizing the least square error of the hourly load and the average daily load.

DEMAND-SIDE BIDDING (DSB)

Customers can play role in consumption management by DSB. Consumers usually offer a price for the amount of required energy to the ISO, and the ISO provides the consumers demand based on their bids taking into account the supply cost and system constraints. In our proposed DSB method, the consumers not only bid the hourly required power and related prices to the ISO but also the load priority by offering three parameters α, β and γ as low, medium and high priorities, respectively. These parameters indicate the participation index of the consumers in Demand-Side Management (DSM). Consumers are needed to offer the desired price of each load priority, namely π_{low} ، π_{med} and π_{crt} respectively. Low priority loads could be curtailed or shifted, while medium priority could only be shifted, meanwhile high priority (critical loads) should be supplied. Increasing α and β increases the share of the consumer participation in the DSM by increasing low and medium priority loads and decreasing the high priority ones.

CASE STUDY AND SIMULATION RESULTS

A low-voltage microgrid with three feeders comprising of residential, industrial and commercial feeders is selected as Figure 5 [13]. Microturbine, fuel cell, wind turbine and photovoltaic cells are available as DERs. It is preferred to use the energy supplied by renewable as much as possible and the shortage is supplied from the grid. All of DERs neither consume nor produce reactive power. It is assumed that the cost of supplied energy by DERs is negligible. In these scenarios the residential, commercial and industrial consumers bid their load to the market in all of the priorities.

Table 1 shows the price-responsive consumer (PRC) bids for each priority of the electric load consumption. The consumers are nominated according to Figure 5, and 100 EVs in six types are assumed as can be seen in the Figure. Table 2 shows the characteristics of the EVs used in the study [15]. Different scenarios are simulated as follows:

- Base Case: The daily load without EVs;
- Uncontrolled charging that EVs on residential feeder

charge upon arrival to the parking lots [16];

- Controlled charging that EVs are charged after peak hours, 3 hours after reaching to the parking lot;
- Smart charging that EVs are charged based on the electricity price to maximize their benefit, i.e., the lowest valley prices are more preferable;
- Demand response scenarios in which the consumer bid prices are applied in the microgrid's operation;
- Smart charging and demand response scenarios that not only smart charging is considered but also the participation of consumers by bidding is appreciated.

These scenarios are compared with the base case to show the impact of proper EV’s charge/discharge management.

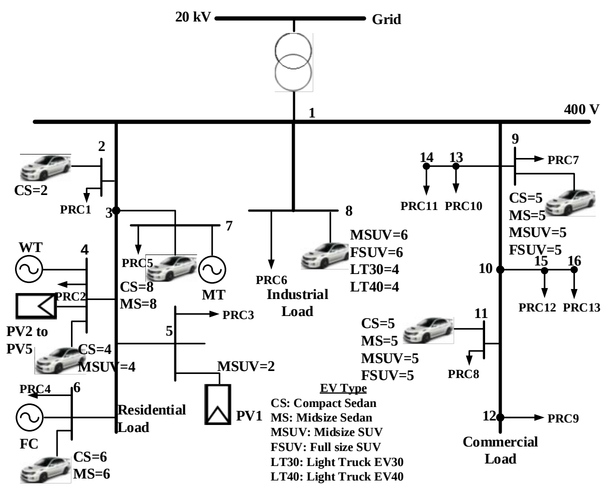

Figure 5: Sample microgrid with EVs at parking lots [14]

Table 1: Price-Responsive Consumer (PCR) bids

Consumers		Consumer Bid (Ect/kWh)		
		Low	Medium	High
Residential Feeder	1	5.98	24.09	100
	2	1.39	40.87	100
	3	3.21	15.36	100
	4	1.53	18.23	100
	5	5.8	14.09	100
Industrial Feeder	6	1.02	13.76	100
Commercial Feeder	7	4.87	39.42	100
	8	5.08	29.28	100
	9	5.34	28.24	100
	10	1.42	14.07	100
	11	2.99	38.85	100
	12	2.29	30.77	100
	13	5	21.28	100

Table 2: Characteristics of the used EVs

Type as Fig.6	Battery pack size (KW)	$I_{batt\_charger}$ (A)	Charging time (from 20%) (h)	Efficiency (%)	SOC at t=0 (%)
CS	5.1	15	3.9 – 5.4	85 - 95	10 - 30
MS	5.9	15	4.4 – 5.9	85 - 95	10 - 30
MSUV	7.7	15	5.4 – 7.1	85 - 95	10 - 30
FSUV	9.3	15	6.3 – 8.2	85 - 95	10 - 30
LT30	11.2	15	6.9 – 8.8	83 - 87	10 - 30
LT40	14.9	15	7.8 – 9.5	80 - 85	10 – 30

Figure 6 shows the base case and uncontrolled/controlled scenarios. Uncontrolled charging causes remarkable increase in the base peak demand, while controlled charging has shifted the EVs’ loads to the low-load periods. Only the EVs available on the residential feeder could be controlled to shift a part of the peak load as the commercial and industrial EVs are charged in the mid-day. Anyhow, the EVs put a significant burden on the grid and increased the gap of the peak and valley.

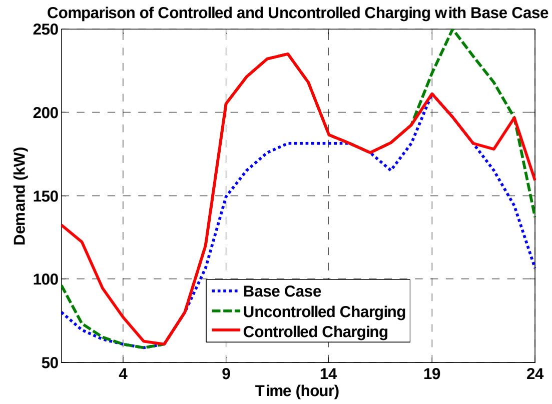

Figure 6: Comparison of the base and uncontrolled/controlled charging scenarios.

Figure 7 shows smart charging/demand response with respect to the base case. As can be deduced from this figure, smart charging mainly has shifted the load to the hours with the least price values without tackling with the peak loads, however, the smart charging with demand response has the tendency to increase the trough and decrease the peak. This scenario is simulated with the data of demand response as Table 3 with the more tendencies toward flattening the load curve.

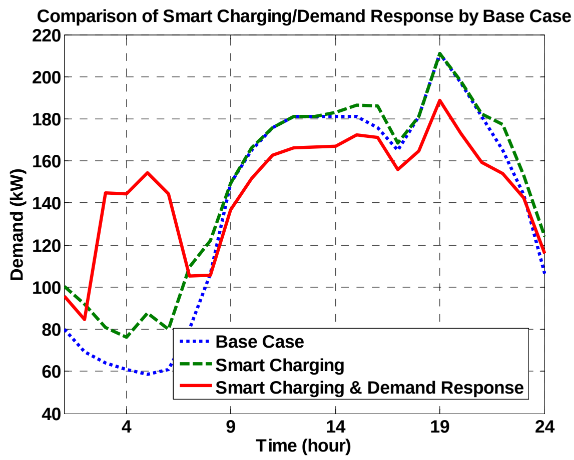

Figure 7: Comparison of the base case, smart charging and smart charging with demand response scenarios.

Table 3: Parameters of demand response in smart charging

Scenario	Residential			Ind.	Commercial	
	α	β	γ	γ	β	γ
Demand response	0.12	0.12	0.76	1	0.12	0.88

Figure 8 shows the results of the proposed method for flattening the daily load curve in the normal charging with DR and also smart charging with DR scenarios. As can be deduced from this figure, smart charging is successful to fill the gap between the valley and peak parts because it tends to charge the EVs at low price hours, however, normal demand response has not fill the trough in the off-peak hours as this method is mainly concentrated on shaving the peak.
It is worth noting that in scenarios that the flattening of the load curve is required, the average price cost of electricity is higher than the scenarios with the aim of maximizing social welfare.

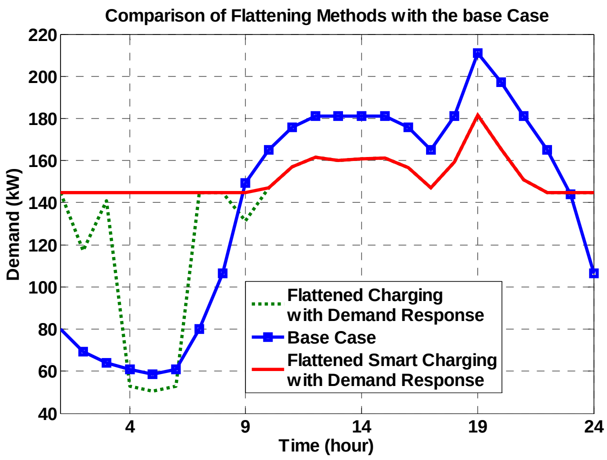

Figure 8: Flattening methods applied on the sample system.

CONCLUSIONS

The impact of EVs on the performance of a microgrid with different consumers and load patterns is investigated. Uncontrolled charging could severely affect the grid by increasing the peak loads and increased prices of supplying demand. Meanwhile, controlled charging would mitigate the burden on the grid and helps to shift the load to off-peak hours. It is shown that smart charging that takes into account the price of energy increases the consumption in low-load periods. Demand response is a powerful tool to shave the peak and fill the trough by maximizing the social welfare without the objective of flattening the daily load curve. The combination of demand response and smart charging is of great benefit to the high penetration level of EVs in the microgrid. A new method is proposed to apply the EVs in order to establish a quasi flat load curve in spite of deviating from minimum prices representing in other scenarios. A sample microgrid with different travelling habits of the EV owners is used to simulate the proposed method.

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