Article

Priority Wise Electric Vehicle Charging for Grid Load Minimization

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Abstract: The number of Electric vehicle (EV) users is expected to increase in the future. The driving profile of EV users is unpredictable, necessitating the design of charging scheduling protocols for EV charging stations servicing multiple EVs. A large EV charging load affects the grid in terms of peak load demand. Electric vehicle charging stations with solar panels can help to reduce the grid impact of EV charging events. With reference to the increasing number of EVs, new technology needs to be developed for charging station and management to create a stable system for users, and electric utilities. The load of a total EV charge can affect the grid, degrading quality and system stability. In this paper, a charging station scheduling strategy is proposed based on the game theoretic approach. In the proposed strategy, with respect to the grid load demand minimization, charging stations have scheduled EV charging times to prevent sudden peak load on the grid the proposed game theory strategy is sudden peak load on the grid. The proposed game theory strategy is defined on the basis of priority so that both grid operators and EV users can maximize their profit by setting priorities for charging and discharging. This work provides a strategy for grid peak load minimization.

Keywords: vehicle to grid (V2G); electric vehicle; peak load; charging priority

1. Introduction

EVs play an essential role in mitigating fossil fuel crises and reducing carbon emissions. In order to effectively exploit their potential as an energy resource, EVs should not only consume energy via charging but also return energy to the grid at peak times [1]. Successful deployment of V2G can help to maintain a balance between consumption and generation. The shifting of loads to non-peak hours or renewable energy sources is essential in a smart grid. The tariff rate for off-peak hours is less than the daytime tariff rate. Therefore, if electric vehicle (EV) users could charge their vehicles during off-peak hours, i.e., nighttime, they could maximize their profit and utility. Currently, utilities provide incentives to EV users to return power back to the grid during peak hours. In this scenario, the aggregator controls the power from EVs to support homes or other vehicles [2]. An EV aggregator acts as an intermediate system between EV users and utilities, controlling the charging and discharging schedule according to constraints. Aggregators optimally regulate the charging plan of EV fleets to minimize total cost, considering EV charging constraints [3]. The distribution system operator restricts EV charging during peak hours, maintaining operational limits but increasing the operational cost of EVs [4–7]. A smart charging control strategy was presented for residential plug-in hybrid vehicles to minimize peak load, involving intelligent scheduling of EV charging to enhance the scope of the smart grid and increase the profit of EV users by charging vehicles during low-demand hours [8,9]. In this paper, we only consider user priority, proposing a charging scheduling model for private areas based on user bidding to increase flexibility and utilization of charging slots [10]. The proposed strategy is designed for coordinated charging/discharging with V2G to increase

parking profit [11]. In this work, we provide information with respect to a strategy for scheduled charging based on trip distance, in addition to explaining fuzzy logic control for grid-to-vehicle and vehicle-to-grid applications [12–14]. We describe a coalitional approach to managing the number of EV charging sessions with a day-ahead algorithm and a game theory approach to EV charging considering single variables only [15,16]. In [17,18], the authors considered the use of multiple charging sources for EVs in order to achieve cost minimization. Therefore, in the present study, we consider the need for multiple EVCSs for scheduled charging with integrated solar energy. Furthermore, it is necessary to consider increasing the profit of EV users, as well as the electricity grid. The main contributions of this paper are outlined as follows:
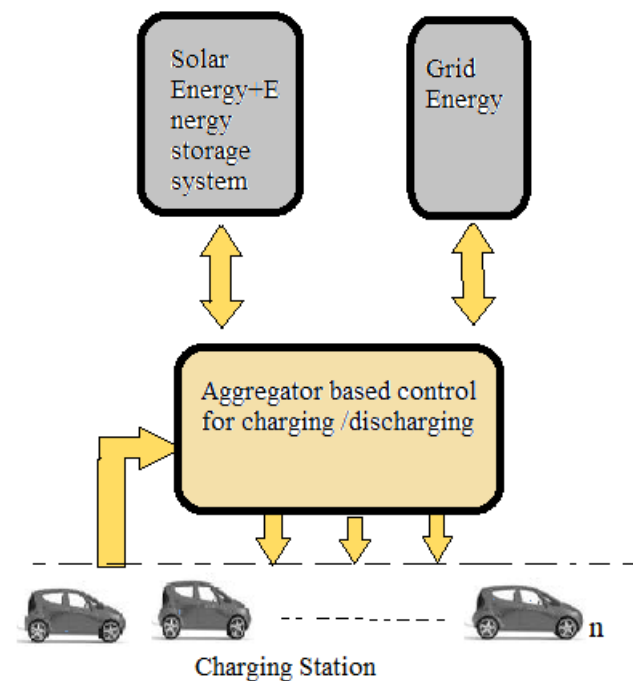
- A priority-based EV charging strategy is developed. This strategy can be used to achieve grid peak load minimization by regulating charging priorities. In this paper, we propose an approach to implementing EV charging stations for multiple EVs with the aim of reducing the load on the power grid;
- We present a scheduling strategy for charging and discharging of EVs based on priority. EV user charging priority is based on user decisions; EV user charging time slots are allocated to users based on the game theory approach. In this paper, we propose a strategy to manage EV load demands to manage the load profile and minimize the cost of charging;
- Multiple priorities considered in this paper depend on the varying charging levels, i.e., slow charging, medium charging, and fast charging. Multiple EVs are considered, and the charging and discharging pattern of EVs is based on the priority level selected by EV users. This strategy is based on cooperative game theory. In this approach, the aim is to maximize profit for the grid operator, as well as EV users;
- A charging station strategy is designed to charge multiple vehicles at a time. Charging slots are allocated according to priority to balance the grid load, considering both user-side and grid-side constraints. Furthermore, to decrease the load on the grid, scheduled operation times are implemented to prevent unexpected peak loads. This can be achieved by shifting EV charging to off-peak hours. EV users can charge their vehicle during nighttime hours through the grid, or organizations can equip facilities with solar rooftops, enabling EV users to charge their vehicles for low rates during off-peak hours. In the latter scenario, stored energy can be fed back to the grid from EVs at workplaces in association with an incentive structure;

This remainder of this paper is organized as follows. In Section 2, we propose an electrical vehicle charging station model and describe its parameters. In Section 3, a game theory base algorithm is described, considering user-side and grid-side priorities. In Section 4, we present case study of charging scheduling during a 24 h period. In Section 5, we present our conclusions.

2. Electrical Vehicle Charging Station Model

The proposed electric vehicle charging station model is designed for 20 EVs with a public charging station providing vehicle-to-grid (V2G) service. With respect to grid power, the charging station is powered by solar energy and is equipped with an energy storage system.

Figure 1 shows the structure of the proposed EVCS, which consists of an energy source solar system (PV) and an energy storage system (ESS). A large number of EV users participate in the proposed strategy, which is controlled by an aggregator through CS that considers the availability of power, as well as EV user requirements. The aggregator collects EV information to generate an EV profile, including information about the user ID and their driving profile. The aggregator can create a calendar to assigned predefined EV charging or discharging slots. EV users can use the booking slots to make multiple charging/discharging requests, e.g., prebooking charging and discharging events. The aggregator continuously checks for prebooked events, based on which it can send messages to EV users, e.g., containing information with respect to free slots and waiting times.

Figure 1. Aggregator-based electric vehicle charging station with an integrated renewable energy source.

In the proposed aggregator-based EV charging control strategy, when an EV user wants to charge their EV, they select a priority group depending on their preference and SOC level. The aggregator continuously monitors charging requirements. EV users can use the calendar to make multiple charging/discharging requests [15,16]. Calendars are scheduled in the cloud, the suitable calendars with optimal waiting times for charging and discharging are sent to EV users. Consider a micro grid in which a solar rooftop and offices contribute to energy production; in this scenario, some users charge their vehicles at nighttime using stored solar energy, and in the daytime, they contribute energy via a V2G system. After charging/discharging the nth EV is remunerated, representing EV user profit. The following assumptions are made in the proposed EVCS model:

The power balance equation for the charging station is expressed as:

$$P_{cs(t)} = P_{grid(t)} + P_{PV(t)} + P_{V2G(t)} \tag{1}$$

where $P_{cs(t)}$, $P_{grid(t)}$, $P_{PV(t)}$, and $P_{V2G(t)}$ are the instantaneous charging station load, grid power, V2G power, and solar power, respectively. P_{cs} depends on the charging power requirement of EV users, which is considered as $SoC_{min} \leq SoC_{(t)} \leq SoC_{max}$, with the following grid power constraints:

$$P_{grid(min)} \leq P_{grid} \leq P_{grid(max)} \tag{2}$$

N = (EV1, where N is set of EVs participating in EV charging. EV2, EV3 ... ., EVn), and n is number of EVs; however, EVs have varying operating ranges and charging priorities, so they are classified into priority groups.

The set of EVs (N) includes two subsets: (i) the charging subset (N^{ch}) and (ii) the discharging subset (N^{dis}). At time period T, the charging demand of EVs is expressed as:

$$EV_n^t \qquad \text{Where } \forall EV_n^t \in N, \forall t \in T$$

Required power for EV charging demand can be calculated as follows:

$$EV_a^{ch,t} = (\text{Capacity of EV battery at time t}) - (\text{Remaining battery power})$$

$$EV_a^{ch,t} = P_{ev1}^t - Rsoc_1^t \tag{3}$$

Then, the demand for discharging $(EV_1^{dis,t})$ can be expressed as Q_{ev1}^t:

$$EV_a^{dis,t} = soc_1^t - Q_{ev1}^t \tag{4}$$

Consider a microgrid in which home and offices with solar rooftops contribute to energy production; in this scenario, some users charge their vehicles at nighttime using stored solar energy and contribute energy to the grid during daytime hours through a V2G system.

$$E_{cs}^t = E_{mg}^t + \sum_{a=1}^n E_a^{dis,t}, \forall a \in N, \forall t \in T \tag{5}$$

The total energy of the charging station is calculated considering the charging requirements of EVs.

$$E_{dem}^t = \sum_{a=1}^n E_a^{ch,t}, \forall a \in N, \forall t \in T \tag{6}$$

The difference between energy supply to the charging station and the total energy demand of the charging station is calculated as the variance:

$$E_v^t = E_{cs}^t - E_{dem}^t \tag{7}$$

$$P_{PV(t)} = N s \cdot N p \cdot P pv \cdot (G(t)/G), \forall t \in T \tag{8}$$

$P_{PV(t)}$ is the total energy contributed by solar sources, whereas Ns and Np are the modules of the PV cell, and G is irradiant power.

Time required to charge EVs is expressed as:

$$Tev = \frac{(Capacity\ of\ EV\ battery) - (Remaining\ battery\ power)}{output\ rating\ of\ charger} \tag{9}$$

$$Remaining\ time\ for\ charging\ each\ EV,\ Ra, t = \frac{t1 - tn}{T} \tag{10}$$

The time required to charge EVs can be calculated by Tev, but main parameter to decide how much time is required to charge an EV battery depends on the SOC of the battery.

The time required for fast charging of single EV is calculated as follows:

$$Tf = \sum_{n=1}^{nf} \left(\frac{N(n) - SOC(n)}{Pnf} \right) \tag{11}$$

where n is the total number of vehicles; V(n) is the rated capacity of a vehicle in kilowatts; n(s), n(f), and n(m) are number of EVs interested in slow, fast, and medium charging, respectively; SOC(n) is the SOC remaining in the nth vehicle; and Pnf is the output required for fast charging in kilowatts (the same parameter can be determined for slow charging and medium charging as shown below).

$$Tm = \sum_{n=1}^{nm} \left(\frac{N(n) - SOC(n)}{Pnm} \right) \tag{12}$$

$$For\ slow\ charging\ Ts = \sum_{n=1}^{ns} \left(\frac{N(n) - SOC(n)}{Pns} \right) \tag{13}$$

In this paper, the cost function is based on time-of-use prize, and dynamic changes in the prize are considered as a function of peak load hours.

$$C_{P1}(t) = \sum_{t=1}^{Tev} (C_{P1}(t) * Tev_{P1}) \dots\dots\dots\dots for\ P1 \tag{14}$$

$$C_{P2}(t) = \sum_{t=1}^{Tev} (C_{P2}(t) * Tev^{P2}) \dots\dots\dots\dots for\ P2 \tag{15}$$

$$C_{P3}(t) = \sum_{t=1}^{Tev} (C_{P3}(t) * Tev_{P3}) \dots\dots for\ P3 \tag{16}$$

Equations (14)–(16) can be used to calculate the cost of charging with respect to the selected priority of charging and discharging.

3. Game-Theory-Based Charging Scheduling for EVs

Game theory is defined as a competitive activity conducted according to a set of rules to maximize the profit of both parties and can be divided into non-cooperative and cooperative games [19,20]. In non-cooperative game theory, one player sets the rules, and the second player follows the rules. In cooperative game theory, both players coordinate to follow the rules to maximize profit. Game theory is a theoretic framework that builds a frame for a situation in which decision makers interact according to a set of rules using a mathematical tool to analyze and make decisions [21]. Players, strategies, and payoff are the parameters of the game theory in which individual players make decisions based on the information provided in the game [22,23]. In cooperative game theory, rules are developed between consumers and an aggregator, with both players trying to maximize their profit. Strategic decision making of users has been widely investigated by observing EV user behavior. Many EV-user-based applications have been investigated to enhance benefits in the economy and energy markets. Game theory has been widely applied to demand-side management [24,25]. For example, all EVs are connected to aggregator 'i', which can take several possible actions in the game (G). The aggregator performs evaluations such that the total demand at time t is supplied within the time requested by EV users [26,27]. The aggregator checks monitors value to manage the load. In the game, the aggregator has access to a set of actions. In the game (G), the goal of the aggregator is to reduce the peak load on the grid by appropriately scheduling EV charging [28].

3.1. EV Use- Side Strategy

When an EV user is in an emergency and wants to charge their EV, an emergency situation can be defined as Wa,t:

$$Wa,t = \left[\begin{array}{l} \frac{Ta,t}{Ra,t}, \ Ta,t \ \leq \ Ra,t \\ 1 \quad , Ta,t \ \geq \ Ra,t \end{array} \right. \tag{17}$$

where Wa,t is the charging need of the a'th number of EV user. The user cost–benefit function (Ca,t) can be defined on two bases: (1) Under, emergency conditions EV users switch to high-priority charging, i.e., $Wa,t = 1$ and $Ca,t = 0$. (2) When the user has a sufficiently charged battery but still wants to complete the charge, they will select low priority by paying less money. User-side strategy priority = (P1, P2, P3)

$$Ca,t\left(EV_a^{ch,t} \right) = Wa,t \left[EV_a^{ch,t} - \frac{\left(EV_a^{ch,t} \right)^2}{2Ep^t} \right] - (1 - Wa,t) \ Ut. \ EV_a^{ch,t}.T \tag{18}$$

In user-side game strategy, we assume that the strategy is selected by a rational user. The user will select a strategy according to their priority; therefore, Equations (20)–(22) provide the constraints for charging speed and charging power for time period t.

$$EV_a^{ch,t} = \text{agr max} = Wa,t \left[EV_a^{ch,t} - \frac{\left(EV_a^{ch,t} \right)^2}{2Ep^t} \right] - (1 - Wa,t) \ Ut. \ EV_a^{ch,t}.T \tag{19}$$

$$0 \ \leq EV_a^{ch,t} \leq 2Ep^t, \ldots t \in Ta \tag{20}$$

$$EV_a^{ch,t} = 0, \ldots t \neq Ta \tag{21}$$

$$SoC_{min} \leq SoC_{(t)} \leq SoC_{max} \tag{22}$$

Assume that P1 has n EV users; therefore, the teamwork function can be expressed according to the game theoretic approach as Equation (17). The EV user priority group can

be divided into subsets, i.e., P = {1, 2, 3, ..., p). For example, a system constraint is the duration of energy generation from solar panels (Tpv). The state of charge (SOC) at a given time (t) should be greater than 30%, i.e., the min SOC; otherwise, life cycles of EV battery will be damaged: SOC min $\leq$ SOC (t). EV users who want to charge their EVs at a low tariff to save money can schedule one day before during off-peak hours. The remaining users with SOC EV $\geq$ SOC 60% can opt for V2G. After priority selection, cost can be calculated by the according to the time-of-use function, i.e., Equation (18).

3.2. Grid-Side Strategy

Grid-side strategy involves maximizing one's own profit in the game for peak load equalization. The aggregator guides each user according to a charging strategy within the grid prediction range. Assume that the gird prediction range is k + 1 for time period T. The charging load on the grid is Pgrid a time t.

$$\text{Pgrid} = \sum_{a=1}^{N} \text{EV}_a^{\text{ch,t}} \tag{23}$$

$$\text{Pgrid} = \sum_{h=0}^{k} \sum_{a=1}^{N} \text{EV}_a^{\text{ch,t}} \tag{24}$$

The grid load can be categorized by type; a conventional load is designated Pot, Pgrid,t is the load at time t, and Pavg,t is the average load on the grid.

$$\text{Pgrid, t} = \text{Pot} + \sum_{a=1}^{N} \text{EV}_a^{\text{ch,t}} \tag{25}$$

$$\text{Pavg t, k} = \frac{\sum_{h=0}^{k} (P_{o\ t+h} + \sum_{a=1}^{N} \text{EV}_a^{\text{ch}}\ t + h)}{k+1} \tag{26}$$

The load balance can be calculated according to the equation shown below. The smaller the load difference (Ft,k), the smaller the load fluctuation.

$$\text{Ft, k} = \frac{1}{k+1} \sum_{h=0}^{k} \left(Pgrid, t - Pavg\ t, k \right)^2 \tag{27}$$

The aggregator sets a strategic tariff rate to influence users to charge during off-peak hours or by solar energy through scheduled charging. The aggregator repeatedly checks for the Pg > Pcs.

Total power demand on grid is expressed by Equation (26).

$$G = (V_1, V_2, \dots V_t) \tag{28}$$

$$Et(V_t) = \sum_{h=0}^{k} (\text{EV}_a^{\text{ch,t}}\ T \cdot V_{t+h}) \tag{29}$$

$$\{V_t + V_{t+1} + \dots + V_t + k\} = \text{agr max} \left[\sum_{h=0}^{k} (\text{EV}_a^{\text{ch,t}}\ T \cdot V_{t+h}) \right] \tag{30}$$

$$0 \leq V_{t+h} \leq V_{\max}, \ h = 0, 1, 2, \dots, k \tag{31}$$

Equation (29) is used to maximize the grid income function. Equation (27) is used to maximize the retailer's income function. Constraint Equation (30) is used to derive the min and max values of pricing. Vmax is set by the grid under peak load demand, so at V max time period, the grid is supposed to provide Pi, P2, P3 strategies to divide the EV charging load on the grid. In this game, the optimal responses of the user and grid are expressed by Equation (30). With consideration of the constraints from Equations (30) and (31), after a number of cycles repetition, a stable state will be obtained.

3.3. Electric Vehicle Charging Station: Priority-Based Strategy

In this section, we explain the various levels of priority. Priorities are set to maximize the profit of EV users, as well as the grid operator. Figure 2, gives the priority-based flow chart of EV user and following are the steps.
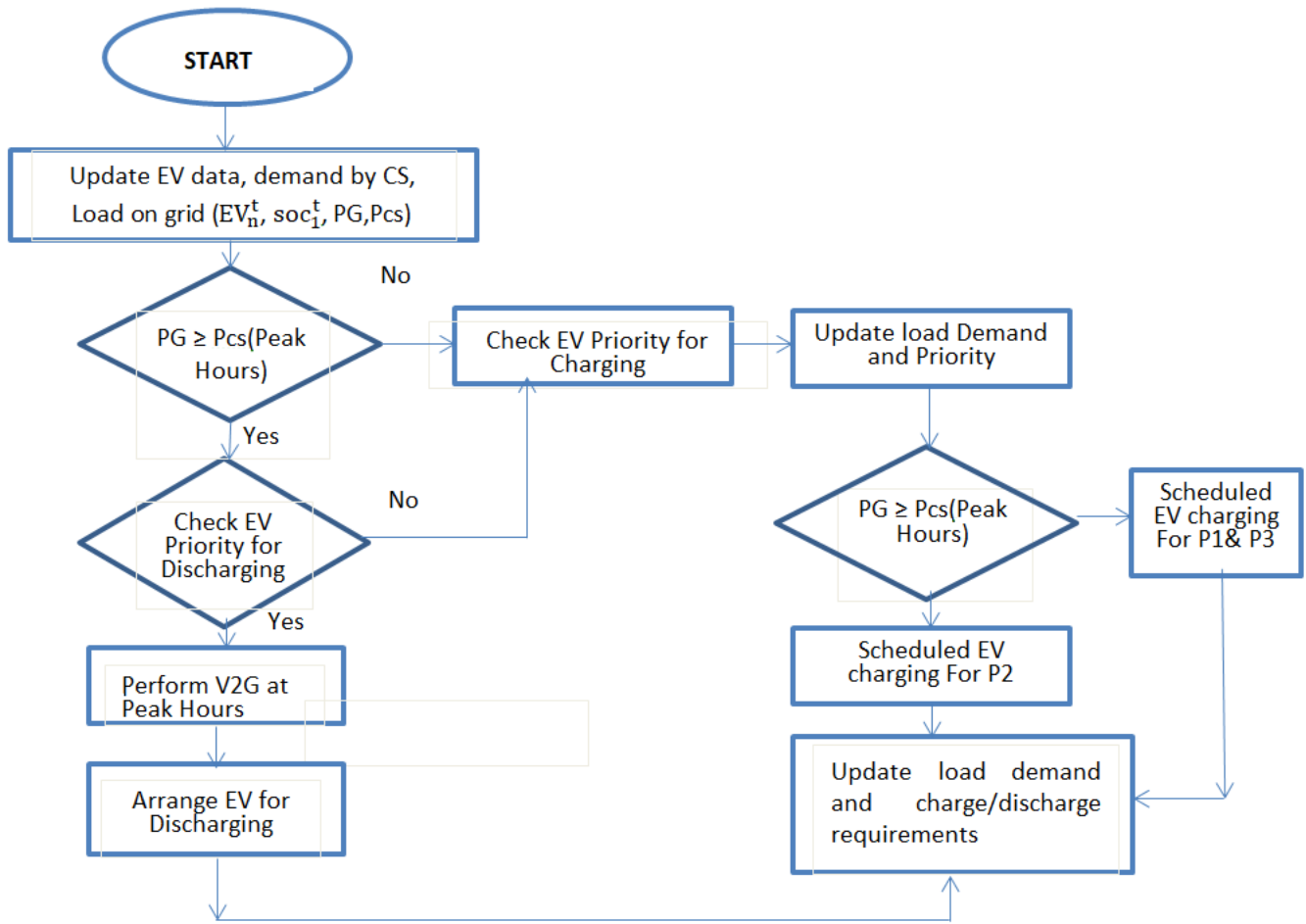
Figure 2. EV user priority-based flow chart.

Step 1: The aggregator initializes the process, collecting supply and demand load data from the grid and from the EVCS;

Step 2: The aggregator checks wither the load on grid Pg > Pcs (peak hours); if yes, then it provides two strategies to EV users to minimize the extra load on the grid.

$$EV_a^{dis,t} = soc_1^t - Q_{ev1}^t \tag{32}$$

$$P_{v2g,(t)} = \sum_{EV=1}^{Nv2g} P_{v2g}(t)\,(EV) \tag{33}$$

If EV SOC (t) > 60%, then the aggregator encourages EV users to discharge during peak hours by providing incentives or by scheduling V2G according to user priority time to send energy back to the grid.

Step 3: If charging is required, then users select a priority level:

Priority 1 (P1) is for charging purposes, allowing EV users to directly charge their vehicles between 8 a.m. and 5 p.m. (solar energy and ESS);

Priority 2 (P2): In this aggregator-based EV charging control strategy, EV users can charge EV between 1 p.m. and 11 p.m. (peak hours) with a medium charging speed or with a high tariff rate for fast charging;

Priority 3 (P3) is for charging purposes, allowing EV users to schedule charging to charge their vehicles at nighttime during non-peak hours.

Priority 4 (P4) is for discharging purposes, allowing EV users to perform V2G during peak hours (1 p.m. to 11 p.m.).

Step 4: The aggregator updates load demand for EV user for charging/discharging and updated for next cycle.

4. Discussion

Table 1 shows the approach values per unit for the proposed electric vehicle charging station (EVCS) model. Per unit values of power are assumed to be the ratio of actual power to base power. The base value for EV charging load on the grid is 270 kw, and the PV base capacity is up to 150 kw, with an energy storage base capacity up to 50 kw. For example, the base value (total EV load) on the grid is 270 kw at 12 p.m. If the EV load is 250 kw, then the pu value will be 250/270 = 0.92 pu. In Table 1, an EVCS model is assumed to form a strategy depending on priority levels. Priority designs are explained in Section 3.3. Assume a grid-connected charging station with averagely moderate charging of 7 kw and fast charging of 45 kw [29]. Let EVs N = 20, with an average daily EV load demand of 220 kw. The above table and flow chart represent an approach to managing an EV charging station with integrated solar energy. Figure 3, in this Figure 3a curve given for the energy demand on grid with respect to day time. Figure 3b EV load Distribution over sources and charging allocation with priority; Figure 3c EV power demand at charging Station.

Table 1. EV charging/discharging scheduling.

Available Sources	Time	EV Load (pu)	Energy Supply from Sources Charging				Discharging
			ESS + Solar (pu)	Grid Power (pu)	V2G Power (pu)		
ESS + Grid	6 a.m.	0.5	0.75	0.03	0	yes	
Solar + Grid	8 a.m.	0.74	0.5	0.3	0	yes	
Solar + Grid	10 a.m.	0.92	0.6	0.48	0	yes	
Solar + Grid	12 p.m.	0.92	0.6	0.48	0	yes	
Solar + Grid + V2G Power	1 p.m.	0.92	0.6	0.3	0.11	yes	yes
Solar + Grid + V2G Power	3 p.m.	0.81	0.6	0.25	0.22	Available with prior priority base and high tariff rate	yes
Solar + Grid + V2G Power / Grid + V2G Power	5 p.m.	0.92	0.6	0.18	0.29		yes
	7 p.m.	1	0	0.5	0.37		yes
Grid + V2G Power	9 p.m.	0.92	0	0.48	0.44		yes
Grid + V2G Power	11 p.m.	0.62	0	0.33	0.29	yes	yes
Grid	1 a.m.	0.44	0	0.44	0	yes	
Grid	3 a.m.	0.18	0	0.18	0	yes	
Grid	5 a.m.	0.11	0	0.11	0	yes	

Assume that an EV is at the station from 3 p.m. to 5 p.m. time; therefore, the EV can sell energy back to the grid during this time. Remaining power of the EV battery, remaining P_{ev} = EV Power (SOC max − SOC min); considered EV power = 10 KW; remaining P_{ev} = 10 (90 − 20) = 7 KW. Then, the EV can send 3 KW to 6 KW of power back to grid; if a minimum 10 EVs take part, then approximately 50 KW of power we can be sent back to the grid during peak hours. The above results are based on the Monte-Carlo simulation in which desired output is determined by summing a set of values [30,31].

Table values are considered from 6 a.m. to 5 a.m. Between 6 a.m. and 1 p.m., the load is managed by solar power. The period between 3 p.m. and 9 p.m. is considered peak load hours, during which time the aggregator encourages users to perform V2G by providing incentives. For example, assume that at 5 p.m. four EV users are present at the charging station with varying SOC levels. The aggregator encourages EV users to perform V2G if their EV SOC is greater than 60%. The aggregator will check the EV user requirements. If charging is required, then the aggregator provides P2 priority to EV users. By providing different strategic options to EV users, the aggregator can shift the peak-hour load on the grid. The simulation generates the output curve for EV load on the grid, power supply,
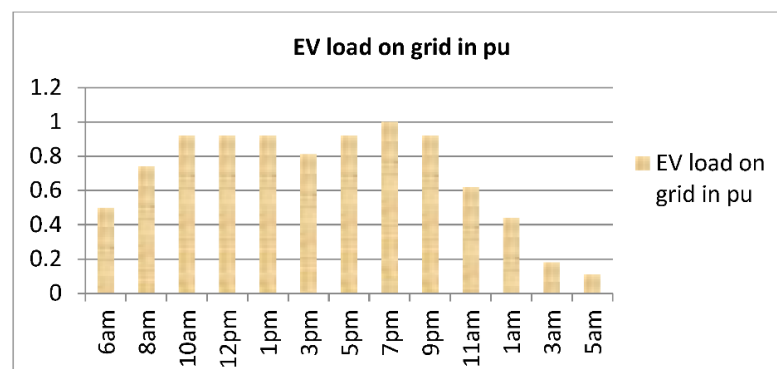
and demand at the charging station. Data in the table is presented per unit. The months of November to May are considered the reference for the above table. Load on the grid is in the Pune, Pimpri region is assumed to be average to high in the afternoon and evening. Figure 3a. Priority-wise charging of EVs can shift EV load from peak hours and minimize the load on the grid during peak hours, as shown in Figure 3b. Figure 3c EV power demand at the charging station. The power demanded on the grid is 0.3 pu at 1 p.m. (peak hour), and with scheduled charging, the maximum EV charging load is divided between solar energy and V2G power. During the same time period (1 p.m.) without the proposed approach, the charging load on the grid is 0.92 pu.
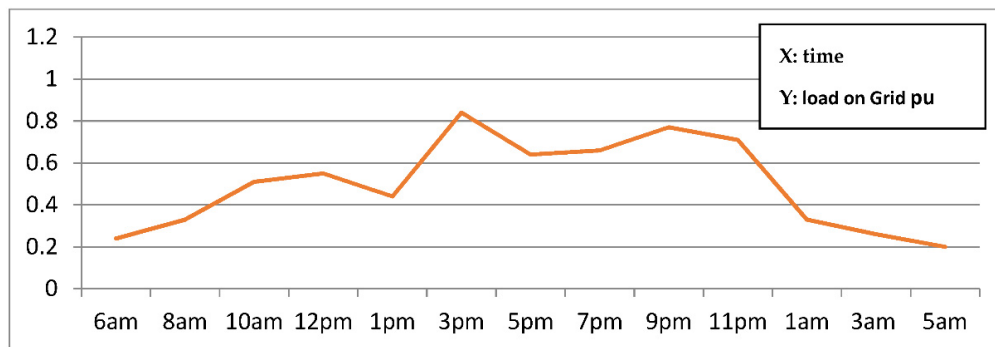
(a)
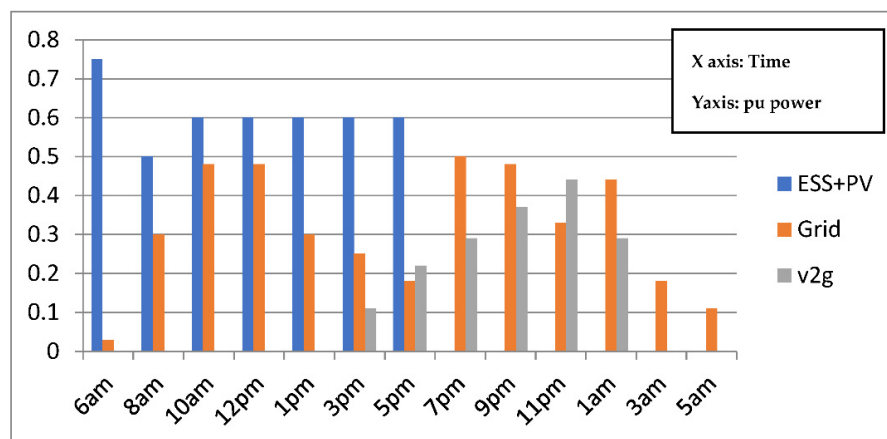
(b)

(c)

Figure 3. (**a**) Daytime on-grid energy demand. (**b**) EV load distribution by sources and charging allocation priority. (**c**) EV power demand at the charging station.

This proposed approach can be applied in the EV sector in the future, when number of EVs is expected to increase. The proposed game theory priority-based strategy can be implemented to maximize the profit of the grid operator, as well as that of EV users. In the future, by using a strong communication network, this approach can be to power a decentralized system.

5. Conclusions

Electric vehicles can play a role of game changer to create a balanced electric network in future by using renewable energy sources. Furthermore, as the number of EVs is expected to increase, proper scheduling is important in the energy supply system. In this paper, we propose a new approach for balancing the grid peak load and scheduling charging according to EV user priority. Selection of priority by EV users will lead to a reduced cost of charging. Varying priority levels can be made available to reduce the peak-hour load on the grid by shifting the load to renewable sources or to off-peak hours for EV charging. This approach can be applied to achieve load minimization. Priority selection by EV users can help to flatten the peak load curve of the grid. Competition between users and the grid can be used to achieve a win–win situation. The game-game-theory-based approach gives provides an opportunity to use renewable energy sources and enhances the use of V2G technology. In the future, additional research should be conducted on cost optimization for EV users based on priority allocation.

Nomenclature

V2G	vehicle to grid
EV	electric vehicle
EVCS	electric vehicle charging station
CS	charging station
PV	solar system
n	number of EV users
a	individual EV user
Tf	time required for fast charging of an EV
Ts	Time required for slow charging of an EV
Tm	time required for medium charging of an EV
Ta,t	time required to charge a single EV during max load hr
$t1$	entering time of an EV at the CS
tn	leaving time of an EV at the CS
$P_{cs(t)}$	instantaneous charging station load
$P_{grid(t)}$	grid power
$P_{PV(t)}$	solar power

$P_{V2G(t)}$	V2G power
$EV_a^{ch,t}$	charging demand by EVs
P_{ev1}^t	capacity of EV battery at time t
$Rsoc_1^t$	remaining battery power
$EV_1^{dis,t}$	discharge demand
Q_{ev1}^t	discharge demand
E_{cs}^t	energy supply to charging station
t	individual time of EV charging/discharging at charging station
Pev	remaining power of EV battery
E_{mg}^t	energy from renewable sources
Ra, t	remaining time to charge each EV
Pg	load on grid
T	total time charging/discharging for an individual EV
CP1(t)	cost to charge as per Priority P1
CP2(t)	cost to charge as per Priority P2
CP3(t)	cost to charge as per Priority P3
k	grid prediction range for EV user
P1	Priority P1
P2	Priority P2
P3	Priority P3
eq	equation
pu	per unit

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