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Electric Vehicle Aggregators in Electricity Markets under Optimal Conditions

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Abstract – **The objective of the proposed scheduling framework is to maximize the revenue of the EVAs while ensuring the fulfilment of charging demands and considering the constraints imposed by the electricity market. The framework takes into account various factors such as electricity prices, EV charging and discharging profiles, grid congestion, and individual EV owner preferences. To achieve the optimal scheduling of EVAs, a mathematical optimization model is formulated. The model aims to find the optimal charging and discharging schedules for the EV fleet, considering the real-time electricity prices and market conditions. Additionally, it incorporates the preferences of EV owners regarding their desired charging durations and departure times. The optimization model is solved using advanced optimization algorithms to obtain the optimal scheduling solution.**

Keywords – **Electric vehicle, Electric vehicle aggregator, electricity, grid**

I. INTRODUCTION

The optimal scheduling of EVAs involves balancing several objectives, including maximizing the revenue generated from participating in electricity markets, meeting the charging demands of the EV fleet, and considering the constraints imposed by the electricity market. These constraints may include dynamic electricity prices, grid congestion, charging infrastructure limitations, and individual EV owner preferences.

This paper focuses on developing a scheduling framework for EVAs in electricity markets under optimal conditions. The objective is to propose a solution that maximizes the revenue of the EVAs while ensuring efficient energy utilization, grid stability, and satisfaction of EV owner preferences. The framework takes into account various factors such as real-time electricity prices, EV charging and discharging profiles, grid congestion levels, and individual EV owner preferences regarding their desired charging durations and departure times.

The study on scheduling electric vehicle aggregators (EVAs) in electricity markets under optimal conditions is conducted to address the emerging challenges and opportunities associated with the integration of electric vehicles (EVs) into the existing electricity grid. This research aims to develop a scheduling framework that maximizes the revenue of EVAs while ensuring efficient energy utilization, grid stability, and satisfaction of EV owner preferences.

II. BENEFITS OF EVA

The benefits of scheduling electric vehicle aggregators (EVAs) in electricity markets under optimal conditions can be numerous. Here are some key benefits:

1. Grid stability and reliability: Optimal scheduling of EVAs helps mitigate the impact of EV charging on the electricity grid. By coordinating the charging and discharging patterns of EVs, grid congestion can be minimized, voltage fluctuations can be reduced, and overall grid stability can be improved. This ensures reliable electricity supply and avoids disruptions or blackouts.
2. Efficient energy utilization: The scheduling framework optimizes the charging and discharging schedules of EVs based on real-time electricity prices and grid conditions. This enables the EVAs to align EV charging with periods of low demand or high renewable energy generation, promoting efficient energy utilization. By strategically managing the charging profiles, excess renewable energy can be absorbed, reducing the reliance on non-renewable sources and promoting a greener energy mix.
3. Revenue maximization for EVAs: By participating in electricity markets and leveraging real-time pricing signals, EVAs can optimize their revenue generation. The scheduling framework considers electricity prices and market conditions to determine the optimal charging and discharging schedules that maximize the revenue potential for the EV fleet. This enhances the economic viability of EVAs and incentivizes their participation in the market.
4. Cost savings for EV owners: The optimized scheduling of EVAs can benefit individual EV owners by

reducing their charging costs. By aligning charging with periods of lower electricity prices, EV owners can take advantage of off-peak rates and cost-saving opportunities. This encourages more EV owners to participate in demand response programs and incentivizes off-peak charging behaviour, which can lead to overall cost savings in electricity consumption.

5. Integration of renewable energy: EVs can act as flexible storage devices that can absorb excess renewable energy during periods of high generation. By incorporating EV charging profiles into the scheduling framework, the integration of renewable energy sources into the grid can be enhanced. This promotes the utilization of clean energy and contributes to the decarbonisation goals of the electricity sector.
6. Enhanced customer satisfaction: The scheduling framework considers the preferences of individual EV owners, such as desired charging durations and departure times. By accommodating these preferences, the framework ensures customer satisfaction and convenience. EV owners can have greater control over their charging schedules and can align them with their daily routines and preferences.
7. Grid Stability and Flexibility: Electric vehicle aggregators can play a crucial role in supporting the stability and flexibility of the electrical grid. By strategically scheduling the charging and discharging of EVs, aggregators can help balance electricity supply and demand. They can shift charging to periods of low demand or high renewable energy generation, reducing the strain on the grid during peak hours. This improves overall grid stability and minimizes the need for expensive grid infrastructure upgrades.
8. Renewable Energy Integration: Optimal scheduling of EV aggregators allows for better integration of renewable energy sources into the grid. Electric vehicles can serve as mobile energy storage devices, absorbing excess renewable energy when it is abundant and feeding it back to the grid during times of high demand. This enables a higher penetration of renewable energy, reduces curtailment, and facilitates the transition to a cleaner and more sustainable energy system.
9. Cost Reduction: By participating in electricity markets, EV aggregators can take advantage of price differentials and optimize charging and discharging patterns accordingly. They can charge EVs when electricity prices are low and discharge during periods of high prices, benefiting from arbitrage opportunities. This can help reduce the cost of EV charging for both aggregators and EV owners, making electric vehicles more economically attractive compared to conventional vehicles.
10. Demand Response: Electric vehicle aggregators can actively participate in demand response programs, responding to price signals and grid conditions. When there is a need to reduce electricity demand to maintain grid stability, aggregators can temporarily curtail charging or reduce the rate of charging for a group of EVs. This demand response capability can support the integration of intermittent renewable energy sources, avoid the need for peaker plants, and prevent blackouts or brownouts.
11. Enhanced Vehicle Utilization: Optimal scheduling of EV aggregators can maximize the utilization of electric vehicle batteries. By actively managing charging and discharging, aggregators can ensure that EVs are charged when necessary while considering user preferences and mobility needs. This can extend the overall battery life, reduce degradation, and increase the value proposition for EV owners.
12. Ancillary Services Provision: Electric vehicle aggregators can offer ancillary services to the grid, such as frequency regulation and voltage support. By adjusting the charging and discharging profiles of EVs in response to grid signals, aggregators can contribute to maintaining grid stability and reliability. This additional revenue stream can help offset the costs associated with EV ownership and charging infrastructure.

III. CHALLENGES

There are a number of challenges that need to be addressed before aggregators can play a full role in electricity markets. These challenges include:

1. Need for clear and consistent policy: There is a need for clear and consistent policy that defines the role of aggregators, and that provides them with the necessary regulatory certainty.
2. Need for market mechanisms: There is a need for market mechanisms that enable aggregators to participate in electricity markets, and that reward them for the services they provide.
3. Need for technical standards: There is a need for technical standards that ensure that aggregators can operate safely and reliably.

As these challenges are addressed, EV aggregators are likely to play an increasingly important role in electricity markets. They have the potential to provide a number of benefits, including:

1. Reduced peak load: Aggregators can help to reduce peak load by shifting the demand for electricity from peak hours to off-peak hours.
2. Improved grid reliability: Aggregators can help to improve grid reliability by providing ancillary services, such as frequency regulation and spinning reserve.
3. Lower electricity prices: Aggregators can help to lower electricity prices by increasing the supply of electricity during peak hours.

IV. RESULT AND DISCUSSION

A.Electric vehicle perspective

EV customers can manage their systems by charging in grid-to-vehicle (G2V) mode and unloading power in vehicle-to-grid (V2G) mode as long as their EV power requirements are not consumed and. EV owners take advantage of this. Each EV must inform the aggregator that they have an availability αt,v ∈ {1,0} (1 if there is a charge/discharge, and 0 otherwise) for a set of periods T at any time t, for each car v in the the list of cars V . During the time intervals (αt,v = 1), EVs must obtain their power for the speed ξv and receive any excess power that the aggregator plans to provide services to the power grid The aggregator is responsible for delivering EV battery will use excess for its economic benefit , to compensate the EV owner accordingly The link between qualifying aggregates and EV owners is outside the scope of this work, and the interested reader is encouraged to search and he does not seek much information.

2. Aggregator's perspective

The aggregate leverages its EV fleet to maximize profitability. Profit is the difference between the income of a system providing services and the cost of providing services. The cost of providing these services is a function of the discharge of the battery. For services from EVs to be economically viable, revenues must be high enough to cover the cost of EV battery disposal. If this is not the case, it does not make economic sense to use EV batteries beyond supplying their mobility needs. The technological potential of EVs to participate in the supporting infrastructure has been demonstrated in the 1000s.

In this work, it is assumed that the aggregator sends upstream and downstream offers to the regulation market. The aggregator may submit a competitive bid to provide part of the legal services, because the SO satisfies its legal requirements by selecting the lowest priced offer If the aggregator bid is accepted, it receives a capacity payment for stand-by status and additional deployment payment in RT when called upon to deploy services.

3.Probability of acceptance and deployment

To form a competing bid pair (i.e. price and quantity), the aggregator must use the probability of acceptance (πa) and the probability of deployment (πd) πa to represent the aggregator's perception of its ability to determine pcap accepted paccept smart in the DA regulation market , ie. Prob(pcap ≥ 0) ≥ π πa Similarly, πd represents the estimated probability of paccepting the compromised real-time system, i.e. prob(0 ≤ pdepl ≤ paccept) ≥ πd, where the PDEPL performs the expected use of an expected mode cannot call the aggregate for movement beyond the capacity accepted by the DA. Since the aggregator does not know which portion of the paccept in the SO RT it can call, the RT must plan to buy the scarcity pshort in the energy market, where pshort = paccept – pdepl and its associated possibilities of this scarcity power Prob (pshort = paccept – pdepl ≥ 0) = 1 – πd = πshort and allows for a combination of risk-free decisions

Figure 1 shows the probability-based decision tree considered by the aggregator in its DA model. In branch (I), the DA power supply is accepted with probability πa. Once the template is accepted, the SO can use it until paccept, i.e., 0 ≤ pdepl ≤ paccept. This occurs with probability πd as shown in branch (II). The aggregator should also consider whether the actual deployment required by the SO exceeds the expected pdepl, and consider the cost of shortage pshort. The best case with no penalty is shown in Figure 2a where the aggregator obtains the DA capacity value λcap for the accepted capacity packcept and the expected RT energy value λRT for the deployment pdepl.

The aggregate in branch (V) expects its DA offer to be accepted with probability πa but the SO does not participate in RT. In this case he cannot use the new revenue for deployment but there is no risk of not being able to deploy if the call SO just gets NEVER accepted offer attribute capacity price λcap. In Branch (IV), the proposal is accepted and it is anticipated that a fully validated capacity will be used. This is done without assuming the expected energy deficit of the aggregator DA since it is able to use its available EVs. The aggregator benefits from both DA capabilities and RTmarket revenue. This is summarized in Figure 2a when pdepl = paccept. Figure 2b summarizes branch (III) with the penalties. In branch (III), the set considers its own part to be complete.

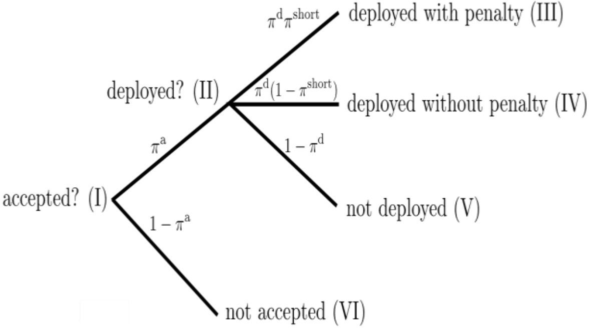

Fig. 1. Decision tree for regulation market interactions

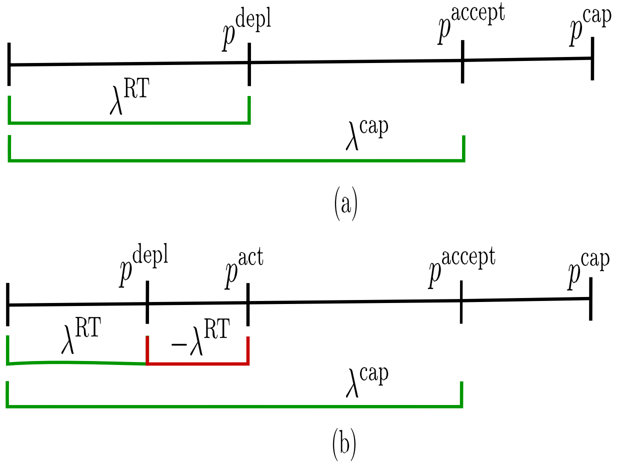

Fig.2. Actual revenues and costs when participating in ancillary markets, where
(a) is the case with no penalties and

(b) includes penalties

The power supply is acceptable and the fraction to be used is at the required pdepl. This occurs because aggregation decisions at DA are based on estimates of its EV fleet at RT. There is therefore a risk of oversupply in the ancillary market, which is admittedly unexploitable due to capacity constraints and so the RT should consider the possibility that actual implementation requirements may exceed they looked at pdepl. In Figure 2b, the aggregator receives DA power income. With respect to RT revenue, the SO has sought a contract which the aggregator cannot provide. Thus, for pdepl, RT obtains the value and the real deficit must be purchased at pact−pdepl λRT. However, in DA, the aggregator already considers the possibility of shortage (pshort) and decisions are protected.

To form a model for studying the range of an electric vehicle by cycles of motion, first of all, for each segment of the cycle time V(t), the values of accelerations necessary to calculate the dynamic force are determined. The acceleration value of the vehicle is the derivative of the speed with respect to time:

dV(t)
a = , m/s (1)
dt

By multiplying the acceleration by the mass of the electric vehicle, taking into account the coefficient of inertia of the rotating parts, the dynamic force is calculated:

$F_d = (1 + \gamma) \cdot m \cdot a$, N (2)

where $\gamma = 0.1$ is the coefficient of inertia of the rotating parts.

To calculate the specific resistance force for each moment of movement of an electric vehicle, it is necessary to add the rolling force Froll to the total air resistance force Fair:

$F_c = F_{air} + F_{roll}$, N (3)

The full force of air resistance is the greater, the higher the speed of movement and the greater the frontal area of the electric vehicle; in addition, the streamlining of the body matters:

$F_{air} = S \cdot k \cdot V^2$, N (4)

where S is the frontal area of the electric vehicle, m2; k is the streamlining coefficient, N•s2/m4 defined as:

$k = 0.5 \cdot C_X \cdot \rho_{air}$ (5)

where ρair = 1.225 kg/m3—air density; CX is the coefficient of aerodynamic air resistance, for the body of a typical electric vehicle we will take CX = 0.35 N•s2/m•kg.

Substituting the parameter values, we obtain:

$k = 0.5 \times 0.35 \times 1.225 = 0.21$ N•N2/m4

The value of the frontal area is calculated by multiplying the empirical coefficient

0.9 by the height of the electric vehicle and the track width (1585 mm):

$S = 0.9 \cdot h \cdot b = 0.9 \times 1705 \times 1585 \times 10^{-6} = 2.43$ m2

The value of the rolling force is: (6)

$F_{roll} = m \cdot g \cdot f_{roll}$, N (7)

where m is the mass of the electric vehicle, kg; g = 9.81 m/s2—free fall acceleration; froll—rolling friction coefficient of the wheel, for roads with asphalt concrete pavement froll = 0.015.

The force realized on the wheel in the traction mode should set the acceleration and compensate for the resistance to movement . However, this formulation is unfair for the coast and braking modes. Expression contains the calculation for the traction, coast down, and braking modes, respectively:

Fd + Fc
Froll = Fc, N (8)
Fd − Fc

Mechanical power consists of the product of the force acting on the wheel and the instantaneous speed of the vehicle :

$P_{mech} = F_k \cdot V$, W (9)

The amount of energy consumed by an electric vehicle in the traction mode is determined by the integral of the traction power over time: Z 0

Econs = Pthrust(t)dt, J t

The amount of electricity generated in braking mode is calculated as: (10)

Z 0
Egen = Pbraking(t)dt, J (11)
t

In Expression (10), Pthrust is the electric power consumed by the electric vehicle in the traction mode, W:

Pcons(mech)
Pcons = (12)
ηred•ηconv•ηmotor

where Pcons(mech) is the mechanical power of the thrust mode, W; ηred, ηconv, ηmotor are the efficiency values of the reducer, converter, and electric motor, respectively.

In Expression (11), Pbraking is the electric power transferred to the battery in the braking mode, W:P braking = Pbraking(mech)•ηred•ηconv•ηmotor, W (13)

where Pbraking(mech) is the mechanical power of the braking mode, W. In the general case, the mechanical power in the braking mode of an electric vehicle is determined as follows. Knowing the mass of the electric vehicle, the initial and final speeds of braking and the time during which the braking was performed, the difference in the kinetic energies of the electric vehicle before and after braking is determined. Further, by dividing the difference by the braking time, the mechanical power in the braking mode of the electric vehicle is determined.

The electric power in the traction mode is greater than the mechanical power due to the losses that accompany the transfer of energy from the electric motor. When braking, the opposite is true. The final energy of the battery at any time is determined by Expression (12), taking into account the modes of traction and braking, respectively:

(Econs
Eult = E0 − ηAccum , J (14)
E0+ Egen•ηAccum

where Eult is final energy of the battery at any time during the driving cycle; E0 is the initial energy in the battery, J; Egen is the amount of electricity generated in braking mode; ηAccum = 97% is the average efficiency of the traction battery.

For a comparative assessment of energy consumption in different conditions, it is attributed to a specific meter. In this case, the specific energy consumption Espec is expressed in Wh/km and is calculated using the formula:

E W•h
Espec = , (15)
3600•l km

where 1/3600 is the conversion factor from J to Wh.

SoC (State of Charge)—the remaining battery charge after overcoming the distance of one cycle of movement relative to full capacity, expressed as a percentage:

Eult •100, % (16)
B. SoC% =
E0

In the simulation model, we consider the law of SoC change depending on the state of charge and mileage in the driving cycle to be linear. The most important indicator in the calculation is the value of the power reserve of an electric vehicle for any cycle of movement. In the model, the power reserve is determined based on the ratio:

l E lc•E
= ; l = , km (17)
lc Ec Ec

where lc and Ec are the distance of one cycle and the values of the consumed energy, respectively; E is the capacity of the traction battery, W•h.

IV. CONCLUSION

The results show that the aggregator derives greater returns from the reserve market than from the energy market for two main reasons.

- Accumulate power money by issuing laws, which do not perish, and.
- Additional revenue is generated if real-time implementation is required.

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