ScienceDirect

Energy
Volume 275, 15 July 2023, 127428

Risk-averse integrated DR and dynamic V2G scheduling of parking lot operator for enhanced market efficiency

S. Sharma [a], Prerna Jain [b]

[a] Department of Electrical Engineering, Swami Keshvanand Institute of Technology, M&G Jaipur, 302017, India
[b] Department of Electrical Engineering, Malaviya National Institute of Technology, Jaipur, India

Received 3 November 2022, Revised 18 March 2023, Accepted 2 April 2023, Available online 7 April 2023, Version of Record 14 April 2023.

What do these dates mean?

Handling Editor: Henrik Lund

https://doi.org/10.1016/j.energy.2023.127428
Get rights and content

Highlights

- V2G Scheduling of PLO considering multiple markets and battery degradation.
- Uncertainty pose financial risk to PLO.
- Designed TOU PBDR for enhanced flexibility from EVs and market efficiency.

- Risk-management is necessary for computing its expected profit and CVaR.
- Sensitivity analysis to parameters' values assess PLO risk-return performance.

Abstract

Parking lot operator (PLO) as an interface between EV owners and System Operator (SO) optimizes V2G scheduling to maximize its profit through multi-markets participation viz. Energy and regulation, while ensuring EVs battery health and daily driving needs. PLO integrates Time-of-Use (TOU) Price-based Demand Response (PBDR) with V2G as more viable tool to unlock V2G potential, alleviate adverse impacts, enhance market efficiency, level load via boosting flexibility to the SO, and reduce charging costs of EV owners. DR integrated V2G scheduling framework is put in jeopardy from EVs' propulsive behaviour and electricity market prices uncertainties, posing financial risk to PLO. In this context, this paper puts forward a risk-averse integrated DR and dynamic V2G decision-making algorithm to maximize the expected profits of PLO. Results of PLO case study with 1000 EVs demonstrate benefits from economies of V2G operations, its resiliency to EVs' behaviour dynamics via sensitivity analysis of risk-averse and risk-neutral PLO performance with respect to round trip efficiency, battery degradation cost coefficient, number of EVs, and upper limit of charging/discharging rates. There is significant 22.2% reduction in cost, 33.82% reduction in revenue, and 14.92% reduction in profit from risk-neutral to risk-averse in V2G mode for charging/discharging rate value 12.1 kW.

Introduction

Dramatic expansion of renewable energy resources is essential to the decarbonization of the power sector, and the inherent variability of many renewable energy sources, like photovoltaics and wind, will demand vast amounts of optimally scheduled energy storage systems of EVs. Massive adoption of EVs is worldwide driving energy security, climate change mitigation, and enhancing system flexibility. EV battery as a flexible demand may participate in electricity market and can be employed as mobile storage if efficiently regulated [1]. EV batteries can provide frequency regulation services and earn revenue [2]. V2G has a potential to maintain the reliability and stability of grid from bi-directional energy flow to/from the grid [[3], [4], [5]]. V2G as an explicit demand side management solution makes EVs as a flexible load and demand-side resource as per their State-of-Charge (SOC) and driving requirements. However, battery degradation critically influences V2G performance. It requires battery degradation cost consideration in V2G scheduling problem formulation [6]. PLO acts as an interface between SO and EV owners to deal with techno-economic concerns inV2G scheduling [7]. PLOs ensure that V2G services do not accelerate EV battery degradation. In addition, PLO is profit-making entity felicitating smart coordination in multiple markets over G2V/V2G operation and control, varying charging/discharging rates sustaining grid stability& reliability. V2G scheduling of a PLO for market participation has been developed in various directions according to perspectives of involved entities SO and EV owners and has evolved into a contemporary issue [24, 50, 51].

Integration of DR as energy management tool can enhance V2G techno-economic efficiency. DR enables collaboration between involved entities (SO & EV owners), reduces SO's investment on peak generation, and increases customer satisfaction by incentivizing in terms of electricity bill savings [8]. Integrated PBDR and V2G scheduling is modelled in [43]. However, Risk-averse behaviour of PLO is disregarded. Mobility behaviour uncertainty influences driving patterns and regulation capacity available with PLO [44]. Besides, for DR integrated distributed V2G scheduling cases, EV owners have more flexibility and can individually decide about their G2V and V2G modes of operation. However, TOU rate not designed in [44] posing financial risk to PLO. [45] considered only SO perspective ignoring multiple markets participation and risk modelling of PLO. Battery degradation costs corresponding to V2G cycling disregarded in [46]. PBDR as a non-dispatchable DR, significantly affect behaviour of EV owners by changing their charging energy consumption in response to time-varying pricing mechanisms. Avoiding EVs recharging concurrently with peak period, encourage peak shaving and shifting [[9], [10], [11]]. TOU PBDR, being less volatile, is an orderly and reasonable electricity price indicator to EV owners and buffers them from RTP dynamics [12,13]. Uncertain parameters raise economic threats to PLO in execution of utility TOU PBDR integrated V2G framework. Specially designed TOU and charging cost constrained V2G scheduling is favourable for improved techno-economic benefits of V2G services, market operational efficiency, EVs utilization, demand response capability thereby alleviating the negative effects on the power grid. For holistic V2G framework, designed TOU-PBDR integration from EV owners' perspective is necessitated [14].

Multiple uncertainties like EVs' mobility behaviour (times of arrival/departure)and market price volatilities pose challenges to the scheduling of PLO for its profit maximization, making it a more complex problem of decision making under uncertainty from a computational perspective [14,15]. Techno-economic analysis of V2G system with PBDR is conducted concerning variation in tariffs [16]. The viability of the V2G-enabled fleet business model is determined through financial risks associated with accelerated battery degradation [[17], [18], [19], [20], [21], [22]]. Operation stability and economic performance of system are improved with optimal bidirectional V2G mode of EVs. However, abovementioned works overlooked DR integration and risk management due to uncertainties. It necessitates developing appropriate decision models to mitigate the V2G services trading risks and provide benefits to different market participants.

Risk assessment is inevitable in an ambiguous background. Several risk assessment methods like robust optimization, probabilistic approach, value-at risk (VaR), and conditional value-at-risk (CVaR) are employed by market operators in the research works [23,24]. [24] modelled stochastic V2G scheduling of PLO in multiple markets considering uncertainties of prices in energy and ancillary service markets. The risk-averse stochastic optimization-based decision framework of PLOs partaking in day-ahead multiple markets viz. Energy and ancillary services (AS) markets are modelled through downside risk control technique CVaR [25,26]. Risk-averse scheduling of V2G and G2V systems enabled EVs is formulated to model the coordination between PLOs and SO [27]. It did not perceive the EV owners' aspect. However, to achieve win-win situation for all involved stakeholders viz. EV owners, SO and PLO, it requires design of TOU rates pertaining to enhance system flexibility by active participation of EV owners in DR integrated V2G scheduling of PLO. In this paper, TOU rates are designed [14] using Agglomerative Hierarchical Clustering Method (AHCM).

Master scepticism and customer distrust of V2G is eminently prevailing, necessitating communication of V2G benefits to EV owners [18,28]. Techno-economic analysis of V2G feasibility is investigated through stochastic approach in Refs. [29,30]. Risk-based V2G/G2V scheduling strategies for the risk-averse and risk-seeker PLO are modelled considering mobility behaviour uncertainty and electricity price volatility in the day-ahead market. Risk-involved stochastic scheduling of PLO in energy and ancillary service markets is studied using CVaR to consider the risk associated with uncertainties of market prices via scenario approach [24,26,and31]]. However, EV owners' perspective and PBDR is disregarded [24,[26], [27], [28], [29], [30], [31]]. The risk-aversion/weighting parameter β expresses the trade-off among expected profit and CVaR. However, the impacts of EVs on distribution network operational constraints are not comprehensively analysed in harmony with EV owners. Also, the DR framework is overlooked from EV owners' perspective.

In this context, this paper puts forward a risk-averse decision-making (RADM) algorithm to maximize expected profits of PLO offering regulation AS to SO for supporting grid stability and avoiding imminent contingencies. Integrated PBDR and dynamic V2G scheduling of PLO can avoid system failure by incorporating flexible behaviour of EV owners. Hence, increased EV owners' participation in V2G service provision in response to attractive charging tariff becomes beneficial for PLO in a smart grid environment. Proposed model uses an efficient CVaR technique to evaluate and formulate financial risks inflicted from multiple uncertain factors, considering system constraints and PBDR. From EV Owners' perspective, energy tariff for charging must be lower than the upper bound of charging cost (CB). In line with this, EV charging cost constraint is deliberated. SOC updating of an EV at time t is based on its connection hours. Additional, congestion management constraint is incorporated to resolve issues such as system overloads and voltage deterioration from coincident charging of large-scale EVs. Five tiered TOU is designed by PLO employing Agglomerative Hierarchical Clustering Method (AHCM) [34] from forecasted RTP [14] accessing historical data from CAPITL zone of NYISO for summer season weekdays in September 2018 [32,33]. V2G prospective to offer grid support AS is typically reliant on Round-trip efficiency (RTE) [35,36]. RTE is the storage metric representing value of V2G technology, defined as percentage of electricity put into EV battery storage that is later retrieved. The higher the RTE, the less energy is lost in the storage process. Sensitivity analysis w.r.t. RTE helps in assessing the riskiness of V2G strategy. Range of RTE is considered (0.7–0.95) for lithium ion battery technology. Proposed work intended to intensify deep insight to V2G RTE by sensitivity of PLO performance w. r.t RTE variation.

Main contributions of the proposed work are:

1) Proposed Risk-averse DR Integrated Dynamic V2G Scheduling framework of PLO models the risks introduced by multiple uncertainties of mobility behaviour and market price volatility using a stochastic programming framework.

2) Scenarios of uncertain parameters are generated using Monte Carlo Simulation (MCS). Probabilistic Kantorovich Distance (KD) matrix is considered in backward reduction algorithm to obtain representative scenarios concerning trade-off among computational speed and accuracy.

3) Incorporating CVaR as a risk measure for modelling and assessment of the financial risks imposed to PLO from multiple uncertain parameters.

4) Special five-tier TOU rates from EV owners' perspective are designed by PLO using AHCM for implementing PBDR.

5) Pragmatic problem formulation capable of decelerating the battery degradation and associated financial risk due to smooth variation of charging-discharging rates.

6) Economies of V2G operations, its resiliency and scalability to EVs' behaviour dynamics for risk-averse and risk-neutral PLOs through sensitivity analysis of PLO's performance parameters RTE, battery degradation cost coefficient (DCC), number of EVs, and upper limit of charging/discharging rates.

Rest of the paper organisation is as follows. The system model for risk-averse scheduling of PLO is involved in Section 2. The detailed problem formulation of risk-averse integrated TOU-PBDR and dynamic V2G scheduling of PLO is discussed in Section 3. The case studies with simulation results are analysed in Section 4. The concluding remarks are made in Section 5.

Section snippets

System model for risk-averse scheduling of PLO

Fig. 1 represents typical architecture of system model for risk-averse scheduling model of PLO. Proposed work highlights risk-based PLO's V2G scheduling in multiple markets reflecting uncertainties of electricity market prices and mobility behaviour. Uncertainty characterization is done using stochastic programming [37]. Incorporation of TOU-PBDR motivates EV owners to recharge their EVs in off-peak intervals in a distributed manner. PLO participation in multiple markets *viz.* Energy and …

Problem formulation

Maximum charging rate limit, $POP^{\max}_{s,i,t}$ is the power needed in s^{th} scenario to recharge the i^{th} EV to its desired SOC in single time interval t as considered subsequently in (4). Here, $SOC_{s,i,t}$ is the SOC level, BC_i is the battery capacity (kWh) and RTE_i is the round-trip efficiency for i^{th} EV battery. The scheduled charging/discharging rate for respective EV in s^{th} scenario should lie within maximum and minimum charging/discharging rate limits in any time slot as (5) and (6) respectively. A …

Simulation and results

The historic energy prices and base-load profile data is acquired as of NYISO CAPITL zone [32,33]. Archived data files provided the market price samples from Ref. [32]. Fig. 3(a) shows the daily electricity wholesale prices in the CAPITL zone of New York ISO market accessed in summer season 2017. Fig. 3b, Fig. 4 respectively depict forecasted prices of the energy and regulation capacity along with the reduced scenarios of prices. A sample case study of 1000 EV owners coming to a PLO for G2V/V2G …

Conclusion and future scope

Massive penetration of EVs poses threats to the system security and reliability. Intuitively, PLO has promising smart coordinator facilitating aggregated EVs multi-markets participation. The recurrent recharge-discharge EVs battery cycling suffers quicker degradation and results in financial threats. DR integrated with coordinated V2G scheduling can address this issue. Optimal partaking of PLO in energy and regulation markets has been studied implementing designed TOU-PBDR from EV owners' ...

Credit author statement

Conceptualization, Methodology, Software, Validation, Analysis, and writing Second author: Supervisor: Writing - Review & Editing; administration. ...

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. ...

Recommended articles

References (51)

X. Lyu *et al.*
Low-carbon robust economic dispatch of park-level integrated energy system considering price-based demand response and vehicle-to-grid
Energy (2023)

A. Alirezazadeh *et al.*
A new flexible and resilient model for a smart grid considering joint power and reserve scheduling, vehicle-to-grid and demand response
Sustain Energy Technol Assessments (2021)

R. Li *et al.*
A novel time-of-use tariff design based onvd Gaussian Mixture Model
Appl Energy (2016)

J. Vuelvas *et al.*
A time-of-use pricing strategy for managing electric vehicle clusters
Sustainable Energy, Grids and Networks (2021)

M.A. Beyazit *et al.*
Cost optimization of a microgrid considering vehicle-to-grid technology and demand response
Sustainable Energy, Grids and Networks (2022)

M.A. López *et al.*

Demand-side management in smart grid operation considering electric vehicles load shifting and vehicle-to-grid support
Int J Electr Power Energy Syst (2015)

L. Noel *et al.*
Navigating expert skepticism and consumer distrust: rethinking the barriers to vehicle-to-grid (V2G) in the Nordic region
Transport Pol (2019)

R. Gough *et al.*
Vehicle-to-grid feasibility: a techno-economic analysis of EV-based energy storage
Appl Energy (2017)

K. Uddin *et al.*
The viability of vehicle-to-grid operations from a battery technology and policy perspective
Energy Pol (2018)

F. Mwasilu *et al.*
Electric vehicles and smart grid interaction: a review on vehicle to grid and renewable energy sources integration
Renew Sustain Energy Rev (2014)

View more references

Cited by (8)

Hierarchical control for collaborative electric vehicle charging to alleviate network congestion and enhance EV hosting in constrained distribution networks

2024, Renewable Energy

> *Citation Excerpt :*
> …Most centralized problems consider the technical limitations of the electricity grid in terms of overload events, loading level, or voltage variation. Being aware of the impact on electric networks, [20] proposes a robust Vehicle-to-Grid (V2G) aggregation algorithm to mitigate voltage and frequency deviations of the grid while the charging cost is minimized. [21] presents a profit maximization for the EV aggregator perspective, including the provision of ancillary services, the optimal V2G dispatch, and the design of ToU prices for EV clusters. [22]…

Show abstract

Cooperative economic dispatch of EV-HV coupled electric-hydrogen integrated energy system considering V2G response and carbon trading

2024, Renewable Energy

> *Citation Excerpt :*

> …It demonstrated that V2G technology can improve grid efficiency and profitability, as well as decrease the expenses for vehicle owners. Sharma et al. [13] integrated price-based demand response with V2G to lower the charging costs for users and enhance the flexibility of EV loads. Zheng et al. [14] explored the significant role of EVs in achieving energy savings through V2G technology across various integrated energy systems.…

Show abstract

A hybrid electric vehicle load classification and forecasting approach based on GBDT algorithm and temporal convolutional network

2023, Applied Energy

> *Citation Excerpt :*
>
> …In addition, the feature selection in algorithms cannot reflect the temporal-spatial load changes and support the EV load resource classification. Since the EV charging/discharging resources are a kind of interdependent resources [19,20], there are numerous studies relying on the aforementioned simulation method to perform mathematical modeling and statistical analysis on the existing EV charging data [21–23]. There are complex internal relations among the various charge and discharge factors, which are subject to strong uncertainties [24].…

Show abstract

Optimal energy management of integrated energy systems for strategic participation in competitive electricity markets

2023, Energy

> *Citation Excerpt :*
>
> …In Ref. [35], CVaR was used to measure the risk over the uncertainties of RDG and power demands in the coordinated operation of a multi-energy microgrid. CVaR was used to evaluate and formulate financial risks resulting from multiple uncertainties in Ref. [36] to achieve risk-averse scheduling of the parking lot operator. In Ref. [37], CVaR was adopted in the energy scheduling solution for island microgrids to handle the risk measure subject to uncertainty.…

Show abstract

Communications and Data Science for the Success of Vehicle-to-Grid Technologies: Current State and Future Trends ↗

2024, Electronics (Switzerland)

Integrating Electric Vehicles to Power Grids: A Review on Modeling, Regulation, and Market Operation ↗

2023, Energies

View all citing articles on Scopus ↗

View full text