Coordinated V2G Scheduling of EV Aggregator with Rooftop Solar Charging Park

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Background

- In global power generation mix scenario towards sustainability, EVs are sustainable only if they are charged from wind/solar power resources [1]
- However, due to inherent intermittency, large scale renewables may place threats to power grid in form of violations of frequency/voltage limits [2]
- It necessitates enhanced flexibility to balance generation and demand, extra reserves, and better generation dispatch capabilities
- Possible solution: Charging flexibility is described as variance of charging duration from total connection hours, to allow EVs' charging at off-peak times or surplus renewable generation [3]
- Problem: EV owners' inconvenience
- EV owners who park their EVs at workplace or carrying out vacation events necessitates charging during peak periods in daytime
- Concentrated simultaneous charging of such multiple EVs at same location thus overloads distribution system & would severely affect its operation and grid stability [4-5]
- EV owner friendly smart grid-to-vehicle (G2V) charge scheduling algorithms are required within parking places near shopping malls and office buildings to manage their energy and ensure that system limits are respected as well [6]

Introduction

- Pragmatically, onboard EVs batteries can be operated either as a provisional resource while discharge (V2G) or a DR provider as a charge load (G2V) for alleviating variability of RE generation [7-9]
- EV owner concerns regarding battery lifetime is challenge for V2G implementation [10]
- Operational challenges in future grid for SO: Intermittency of RES & EVs charging/discharging scheduling
- Possible Solution: Smart coordinated scheduling by EVA between SO and EV owners to offer ancillary services & synergize grid integration of RES & EVs G2V2G technology
- proposed work aims an effective utilization of intermittent PV generation from rooftop solar charging park & maximization of EVA's profit
- It provides congestion management, through TOU-PBDRP & considering system (transformer delivery capacity & baseload profile) constraints presented by SO
- Revenue of EVA is due to regulation services to SO & charging services to EV owners
- Operational cost of EVA considers cost of procuring EVs' charging energy requirements from wholesale electricity market for EVs' charging & battery degradation cost while ensuring EV owners' driving necessities
- Efficacy of model is validated through simulation results analyzing two cases: with and without PBDRP
- Proposed model would help SO to maintain technoeconomic consistency by increase of PV integration, & peak load management

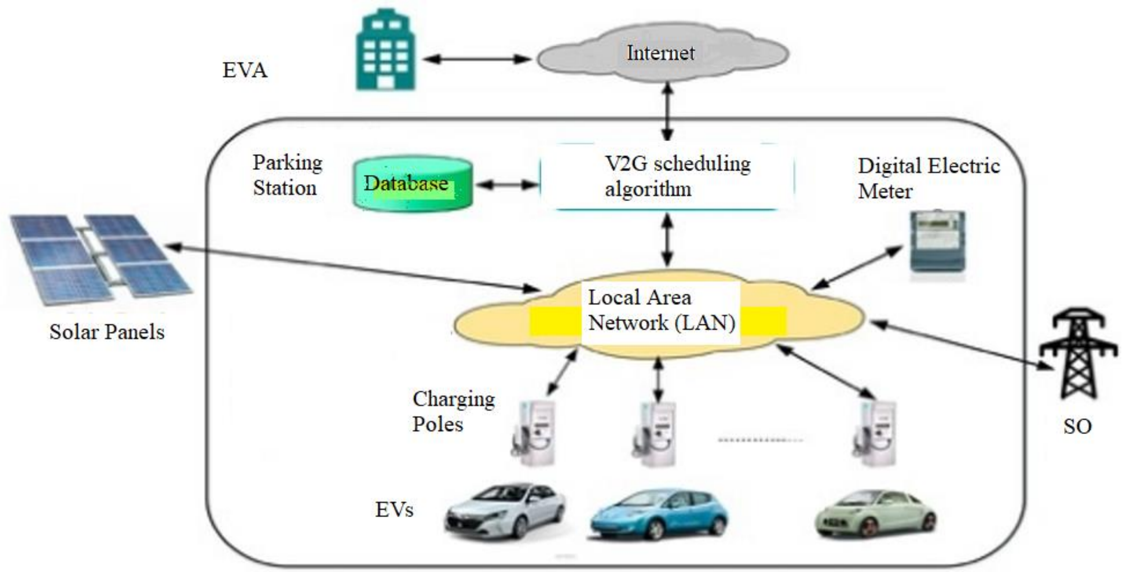
Possible EVs scenarios

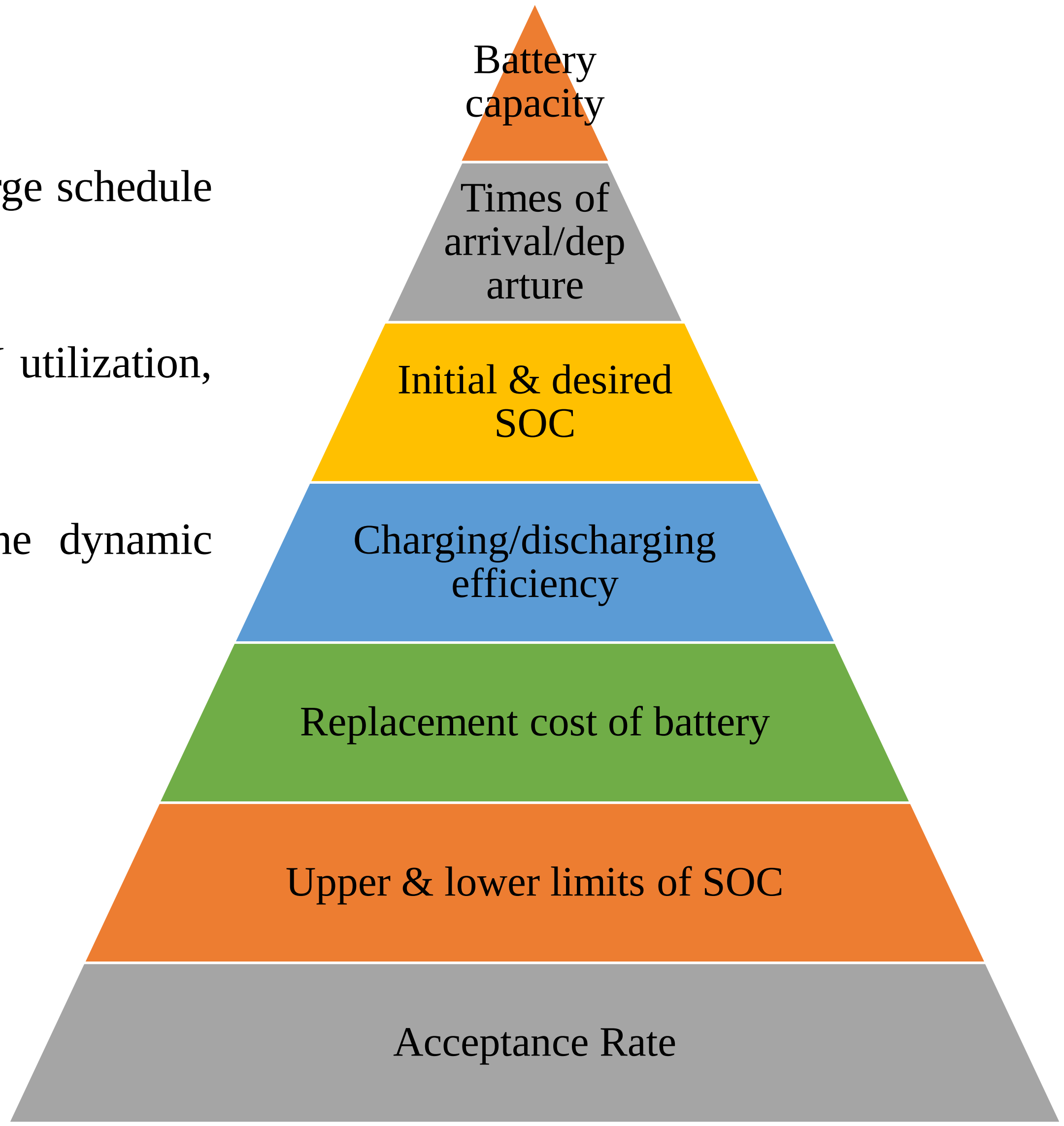
	Real-time Communication w/ Utility	Cheaper Fuel for Customers	Timed Charging	Back-up Power	Unidirectional Ancilliary Sercies	Bi-Directional Ancilliary Services	Off-Peak Load	Load Shifting for Wind Firming
V0G		√						
TC		√	√					
V1G	√	√	√		√		√	
V2B		√	√	√			√	√
V2G	√	√	√	√	√	√	√	
V2G NGU	√	√	√	√	√	√	√	√

- In G2V mode, EVA modulates rate of charging to lower value during peak load period to meet SO's necessities and to higher value under surplus renewable generation
- With V2G, electricity can be stored in the EV & returned to grid as needed during peak times
- V2G technology provides DR facilities to SO for improving grid's economic efficiency by satisfying large electrical load demands in homes or offices during peak times
- Managing DR service by an EV battery represents some specific system & contracted EV owners' (respecting a minimum number of connection hours per day in service) constraints
- Every dispatch order must match power capacity of line & EV's level of charge called SOC; EVA & SO can no longer ask for down regulation beyond battery full charge as well as no further injection into the grid beyond battery dead level

Proposed System Model

- PV generation & electricity price for upcoming day is forecasted
- Using EV profile information, EVA regulates the EVs' charge/discharge schedule for upcoming day
- Aiming at minimization of EVs' charging cost, maximization of PV utilization, and minimization of charging load on the grid
- Static V2G model results could be utilized for evaluation of the dynamic scheduling model's performance.





EV profile information

Problem Formulation

$$h_{i,t}, u_{i,t}^{G2V} \in \{0,1\} \ \forall i,t$$

$$POP_{i,t}^{V2G}, POP_{i,t}^{G2V}, ruc_{i,t}, rdc_{i,t}, h_{i,t} = 0 \ \forall t < t_{a_i}$$

$$POP_{i,t}^{V2G}, POP_{i,t}^{G2V}, ruc_{i,t}, rdc_{i,t}, h_{i,t} = 0 \ \forall t > t_{d_i}$$

$$P_i^{\min} \cdot u_{i,t}^{G2V} \le POP_{i,t}^{G2V} \le P_i^{\max} \cdot u_{i,t}^{G2V} \ \forall i,t$$

$$P_i^{\min} \cdot \left(1 - u_{i,t}^{G2V}\right) \le POP_{i,t}^{V2G} \le P_i^{\max} \cdot \left(1 - u_{i,t}^{G2V}\right) \forall i,t$$

$$SOC_{i,t} - SOC_{i,t-1} = \left(SOC_i^{Des} - SOC_i^{INI}\right) \Big/ \left(td_i - ta_i\right)$$

$$SOC_{i,t} = 0, \ t < t_{a_i}$$

$$SOC_{i,t} = SOC_i^{INI}, \ t = t_{a_i}$$

$$SOC_{i,t} = SOC_i^{Des}, \ t = t_{d_i}$$

$$SOC_{i,t} \ge SOC_i^{min}, \ \forall t \ge t_{a_i}$$

$$SOC_{i,t} \le SOC_i^{\max}, \ \forall t \ge t_{a_i}$$

Problem Formulation

$$SOC_{i,t} = SOC_{i,t-1} \cdot h_{i,t-1} + \begin{pmatrix} POP_{i,t}^{G2V} \cdot u_{i,t}^{G2V} \cdot \dfrac{\eta_{ch}}{BC_i} \\ -\dfrac{POP_{i,t}^{V2G} \cdot \left(1-u_{i,t}^{G2V}\right)}{\eta_{dch} \cdot BC_i} \end{pmatrix} \forall i,t$$

$$Pm\max_{i,t} = \frac{\left(SOC_i^{DES} - SOC_i^{INI}\right) \cdot h_{i,t} \cdot BC_i}{\eta_{ch}}$$

$$\sum_{i=1}^{N} POP_{i,t}^{G2V} + Load_t + \sum_{i=1}^{N} dc_{i,t} \leq TDC$$

$$PV_t + \sum_{i=1}^{N} \left(1-u_{i,t}^{G2V}\right) \cdot POP_{i,t}^{V2G} + \sum_{i=1}^{N} uc_{i,t} = Load_t + \sum_{i=1}^{N} u_{i,t}^{G2V} \cdot POP_{i,t}^{G2V} + \sum_{i=1}^{N} dc_{i,t}$$

$$uc_{i,t} = POP_{i,t}^{V2G} \cdot \left(1-u_{i,t}^{G2V}\right)$$

$$dc_{i,t} = \min\left(Pm\max_{i,t}, P_i^{\max}\right) - POP_{i,t}^{G2V} \cdot u_{i,t}^{G2V}$$

Problem Formulation

$$\mathrm{Revenue} = \sum_{i=1}^{N}\sum_{t=1}^{T}\left(dc_{i,t}\cdot RDP_t + uc_{i,t}\cdot RUP_t\right) +$$

$$\sum_{i=1}^{N}\sum_{t=1}^{T}\left(M_k + EP_t\right)\cdot POP_{i,t}^{G2V}\cdot u_{i,t}^{G2V}\cdot h_{i,t}$$

$$\deg_i = \left(0.042\cdot Batc_i/5000\right) + \left(0.15\cdot\frac{\left(1-Ef_i^{\,2}\right)}{Ef_i}\right)$$

$$Cost_{\deg} = \sum_{i=1}^{N}\sum_{t=1}^{T}\deg_i\cdot\left(1-u_{i,t}^{G2V}\right)\cdot POP_{i,t}^{V2G}$$

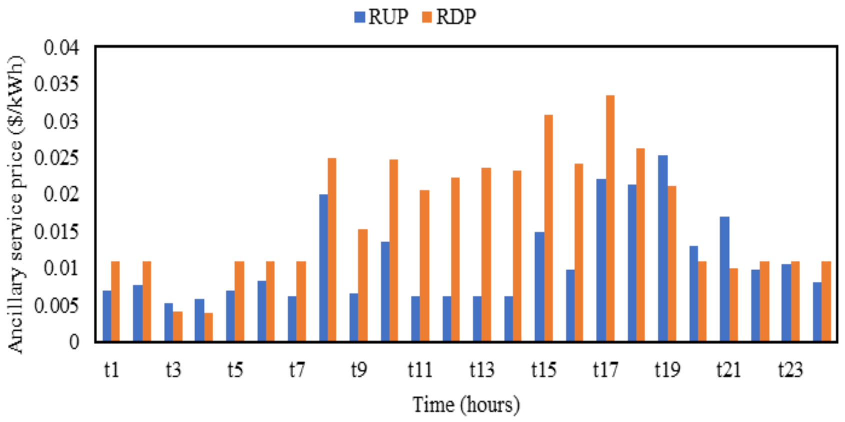
$$Cost = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}POP_{i,t}^{G2V}\cdot h_{i,t}\cdot EP_t^{RTP}\right) + Cost_{\deg}$$

$$\max \mathrm{Profit} = \max\left(\mathrm{Revenue} - Cost\right)$$

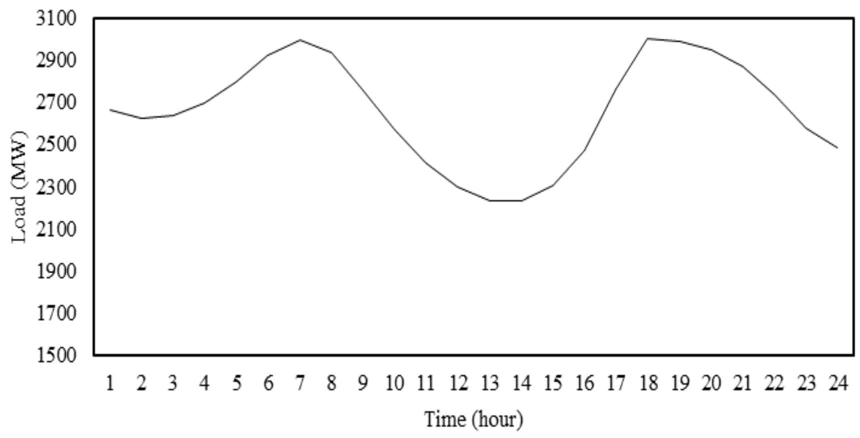
EV & Market Information

EV CHARACTERISTICS

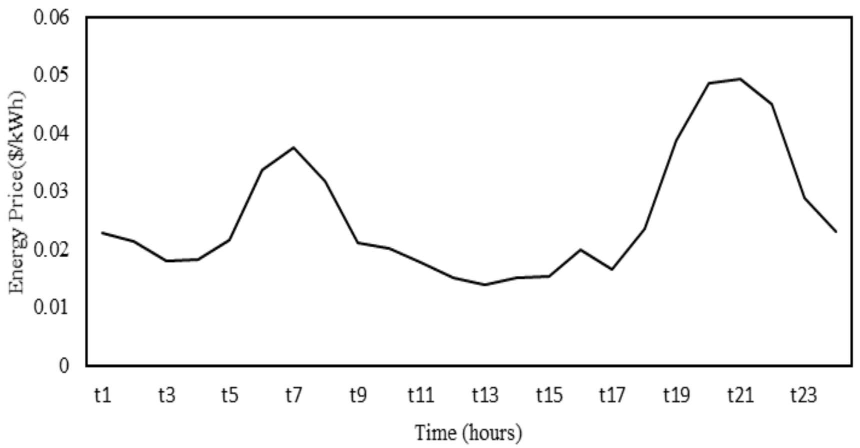
Vehicle	Battery Capacity (kWh)	Charger Capacity (kW)	Battery Cost ($)
Tesla Model S	80	15.4	13000



Prices of ancillary service from CAISO market

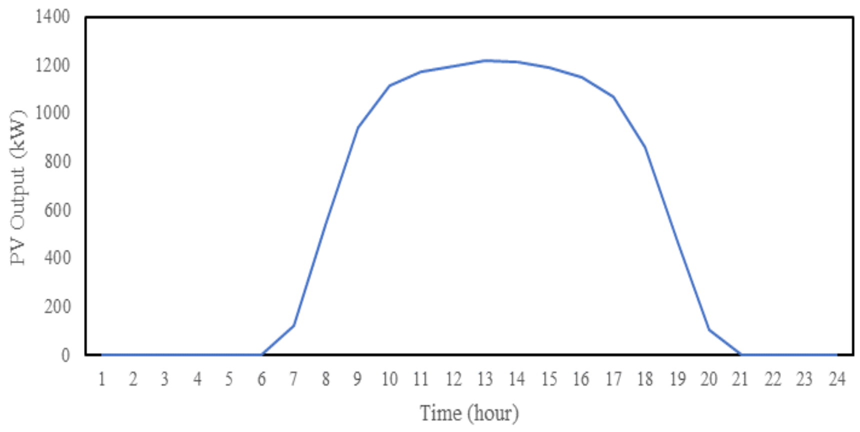


Base load profile from SO

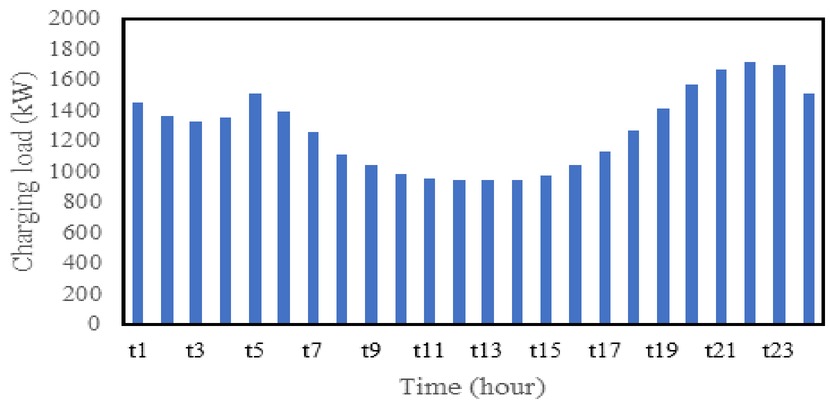


Hourly energy price in ($/kWh)

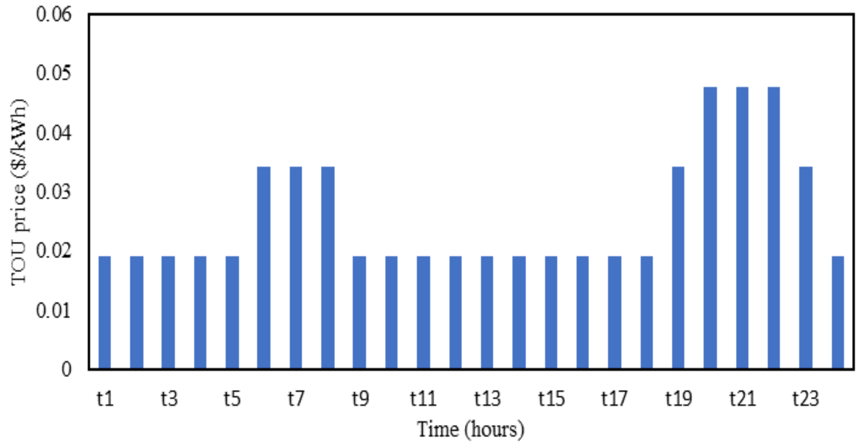
Results & Discussion



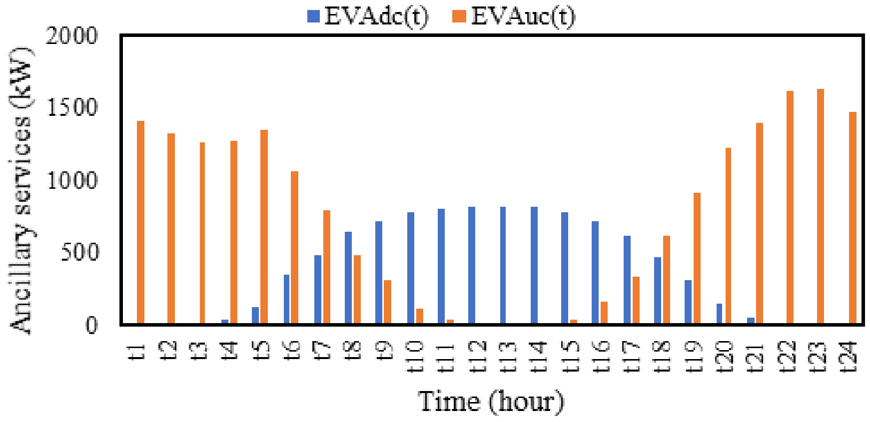
Output Power from PV based parking at workplace



Charging load in kW

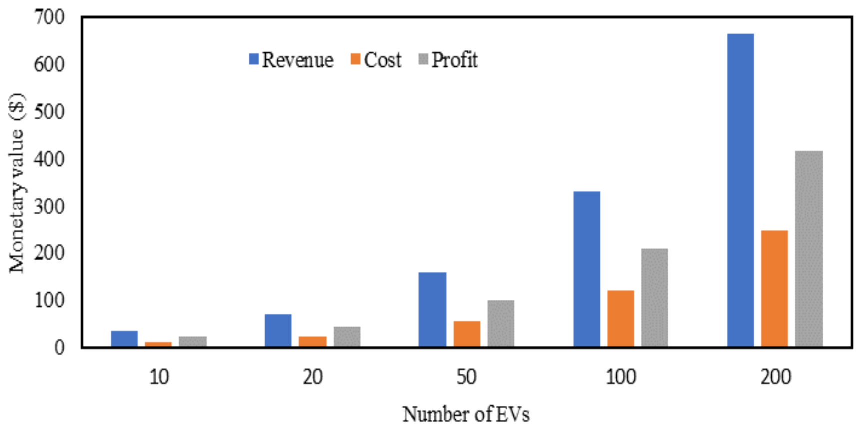


TOU price designed by EVA from hourly energy price in ($/kWh)



Ancillary services provided by EVA in kW

Performance metrics of EVA with & without TOU-PBDR



Performance metrics of EVA: Cost, Revenue, and Profit in $

	Without TOU-PBDR	With TOU-PBDR
Cost ($)	247.8389062	249.5389315
Profit ($)	414.7210377	423.7334832
Revenue ($)	662.5599439	673.2724148
Charging Cost ($)	413.7412	413.1113

EV owner’s average charging cost reduces by 15%

EVA’s profit increases by 2.173% which depends on variation of TOU (selling price) as compared to RTP (buying price)

EVA earns more revenue from selling of regulation services

Has potential to recover operational cost of V2G

Conclusion

- Proposed integrated TOU-PBDR V2G scheduling strategy has great potential to provide grid support regulation services by parked EVs
- It recovers operational cost of EVA with self PVs generation, by the revenues generated from discharging EVs' stored energy to grid on peak hours
- Simulation results validated the efficacy of proposed method in efficient utilization of PV output power to charge parked EVs and lessen the negative impacts on system
- In addition, EV owners are satisfied with desired SOC at reduced charging tariff and battery health requirements
- Proposed work has capability to provide technoeconomic benefits to all involved entities: EVA, EV owners and SO.
- As the future work, this paper can be extended by incorporating the effects of the satisfaction index of EV owners for charging EVs, mobility uncertainty, probability of unexpected trips, under dynamic V2G scheduling model
- Further, EVA's financial risk due to uncertain market prices can be modelled to get trade-off among profit and risk.

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