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E-mobility: A shifting paradigm of consumers towards EV-prosumers

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Abstract

Limited awareness on personal and societal benefits for adoption of E-vehicles (EVs/PHEVs) is hindering their wider adoption and limiting their ability to maximize their ownership of E-vehicles. We developed a model wherein consumers can maximize their utility through energy exchange under vehicle-2-grid (V2G), vehicle-2-home (V2H) and vice-versa using a bi-directional network. Homes without any potential for behind the meter generation can thus participate in the distributed energy market (DEM). A comparative analytical framework is used to empower the consumer to become an EV-prosumer, enabling them to maximise their payoff through their participation in the distributed energy market. We consider scenarios wherein an inactive consumer turn up as EV-prosumer has, (ii) single EV, (iii) two EVs, and compare their incremental payoff. Results reveal increase in consumer's payoff with higher incremental gain for a single EV-prosumer than the one with two EVs.

Introduction

The rising concern on the significant contribution of vehicular emissions to greenhouse gasses (GHGs) and poor urban air quality highlights the need for an environmentally sustainable transformation in the transportation sector. Many of the developed and developing countries are pushing for a greater adoption of e-mobility to decarbonize the sector in order to meet the world climate change targets formulated in COP 21 at Paris [1].

E-vehicles allow consumers to contribute in mitigating the impact of GHGs thus leading to a societal benefit as a whole. In this work, we are defining consumers as active and inactive consumers followed by active and inactive prosumers respectively as depicted in figure.1. The more aware and energy responsive consumers are active consumers who respond to the demand response (DR)/time-of-day (ToD) based programs. It is a volunteer based participation where active consumers agree to shift their load to off-peak hours from peak hours in exchange of incentive as their personal benefits. The active consumers who are equipped with renewable energy resources (RES) such as small-to-medium wind farm, solar photo voltaic and/or e-vehicles and producing self-energy, have recently emerged as a new market players known as prosumers. The prosumer may opt to participate in the distributed energy market (DEM) to sell the surplus quantity in his/her neighborhood to maximize the payoff.

Unlikely active consumers, inactive consumers are completely dependent on the distributed grid for their basic energy demand. However, presented work debate on how e-vehicle enables the inactive consumers to emerge as an EV-prosumer using e-vehicle as energy storage. Further, they can store energy during off-peak hours and sell the surplus quantity back to the grid during peak hours under smart grid environment. Therefore, inactive EV-prosumers can too maximize their payoff thus can contribute in the society in terms of health and other associated benefits [2]. From our perspective this one of it's own type of study that has not been addressed before in the existing literatures.

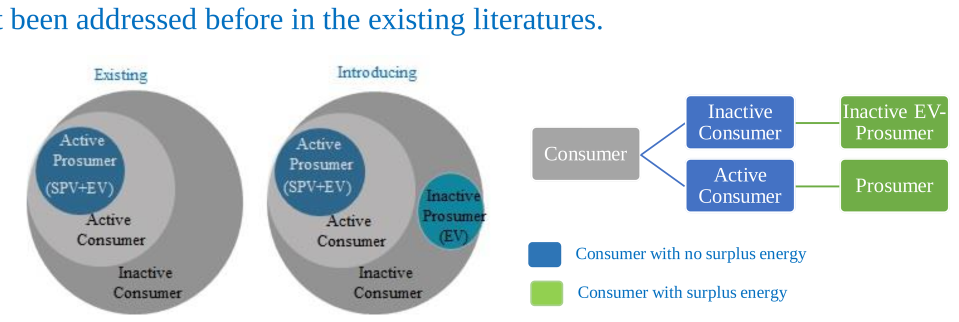

Fig.1 Consumer distribution in a distributed energy market

Motivation and Objective

- The increasing impact of GHGs degrading the environment day by day and emergence of EV-prosumer at major scale can bring numerous benefits to the society such as purifying air-quality, health benefits etc.
- Consumers can solely manage their consumption using V2G and V2H during peak and off peak time to maximise their payoff, who are otherwise not interested in revealing their consumption data to the distribution utility by not agreeing to participate in any of DR based programs like direct load control programs etc.
- To empower the inactive consumers to emerge as market leader exclusively to those who are not equipped with any RES due to different spatial-temporal constraints, by participating in DEM to sell the surplus storage during peak hours to reap maximum benefit out of it.

We aim to develop an optimisation model to uplift the consumer's attitude through introducing the personal and societal benefits associated with the e-vehicles

Contribution

- We propose an algorithm for adoption of E-vehicles to encourage the inactive consumers to manage their energy consumption behaviours without revealing their consumption data to the distribution utility.
- In our system model, the inactive consumer emerging as EV-prosumer can have flexibility to take decision to shift their consumption to have a maximum payoff.
- We model the change in consumer's utility by reflecting the increment in consumer's payoff when emerging as EV-prosumer from inactive consumer.
- This study shows that emergence of EV-prosumer opens up a completely new market prospects for inactive consumers unlike before to participate in DEM through selling back storage energy during peak hours.
- Therefore, with this study we aims to encourage the consumers for their emergence as EV-prosumers that would maximise their payoff irrespective of demographical spatial and temporal constraints which too has an additional potential society benefits.

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Methodology

The system model is defined as follows

$$\max_{x,y} F(x,y)$$

Subjected to, $g_k(x,y) \leq b_k; \quad \forall\, k \in K$

$h_l(x,y) = a_l; \quad \forall\, l \in L$

The function holds the concavity condition, if,

$f[\theta x + (1-\theta)y] \geq \theta f(x) + (1-\theta) f(y) \qquad$ for $0 \leq \theta \leq 1$

Using a Lagrange dual decomposition, $L(Z,\lambda,\mu) = F(x,y) + \lambda * (g_k(x,y) - b_k) + \mu * (h_l(x,y) - a_l)$;

$g(\lambda,\mu) = \max_{z} L(Z,\lambda,\mu)$;The final Lagrange dual problem, $D(\lambda,\mu) = \min_{\lambda \geq 0,\mu} g(\lambda,\mu)$;

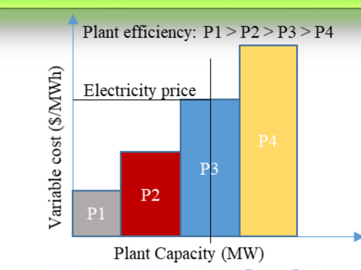

Fig.2: Merit order dispatch

Proposition: The weak slater's condition is reduced to feasibility for affine inequality and equality constraints.

Note: As shown in fig.2, plant 4 is the most inefficient plant. It is scheduled during peak hours to meet the consumers' demand. Therefore, discharging of EVs during peak hours serves the benefit to the society in terms of reducing GHGs emission.

Equation Used

- ***Utility function***

$$U^t(\omega, {q_{sc}}^t) = \begin{cases} (\omega * {q_{sc}}^t - \theta * (q_{sc}^t)^2 \,| & {q_{sc}}^t \leq \omega/_{2\theta} \\ ((\omega)^2/_{4\theta} \,| & {q_{sc}}^t \geq \omega/_{2\theta} \end{cases}$$

[ω:behavioural parameter; q_{sc}^t:self-consumption]

- ***State of charging of EVs***

$soc(t+1) = soc(t) + \eta_{EV} * B * CR$; *[η: battery efficiency; B: battery capacity; CR: charging /discharging ratio]*

- ***Societal welfare***

$\Pi(\Theta_{EV}^t) = \beta * \Theta_{EV}^t - \alpha * (\Theta_{EV}^t)^2$; *[$t \in (T_{offpeak}, T_{peak})$| vehicle is at home]*

- ***Welfare function***

$$W = \sum_{t \in T_{offpeak}} [U^t(\omega, {q_{sc}}^t) - P^t * D^t] + \sum_{t \in T_{peak}} [U^t(\omega, {q_{sc}}^t) + (P^{T_{peak}} - P^{T_{offpeak}}) * {q_{sc}}^t + \Upsilon^t + \Pi(\Theta_{EV}^t)] - cost * m;$$

$$D^t = q_{sc}^t + \sum_{EV}[soc_{EV}(t+1) - soc_{EV}(t)]; \; \Upsilon^t = \begin{cases} fit * q_{ss}^t \,| & q_{sc}^t \leq \sum_{EV}(\Theta_{EV}^t) \\ P^{T_{peak}} * (-q_{ss}^t) \,| & o/w \end{cases}; \; q_{ss}^t = [\sum_{EV}(\Theta_{EV}^t)] - q_{sc}^t;$$

P: grid price of electricity ($/kWh); D : demand; fit: feed-in-tariff; q_{ss}^t=surplus storage; m= battery maintenance; Θ= battery discharging rate

Results and Discussion

Case i: Consumer without EV : Inactive consumer (Non-participating)

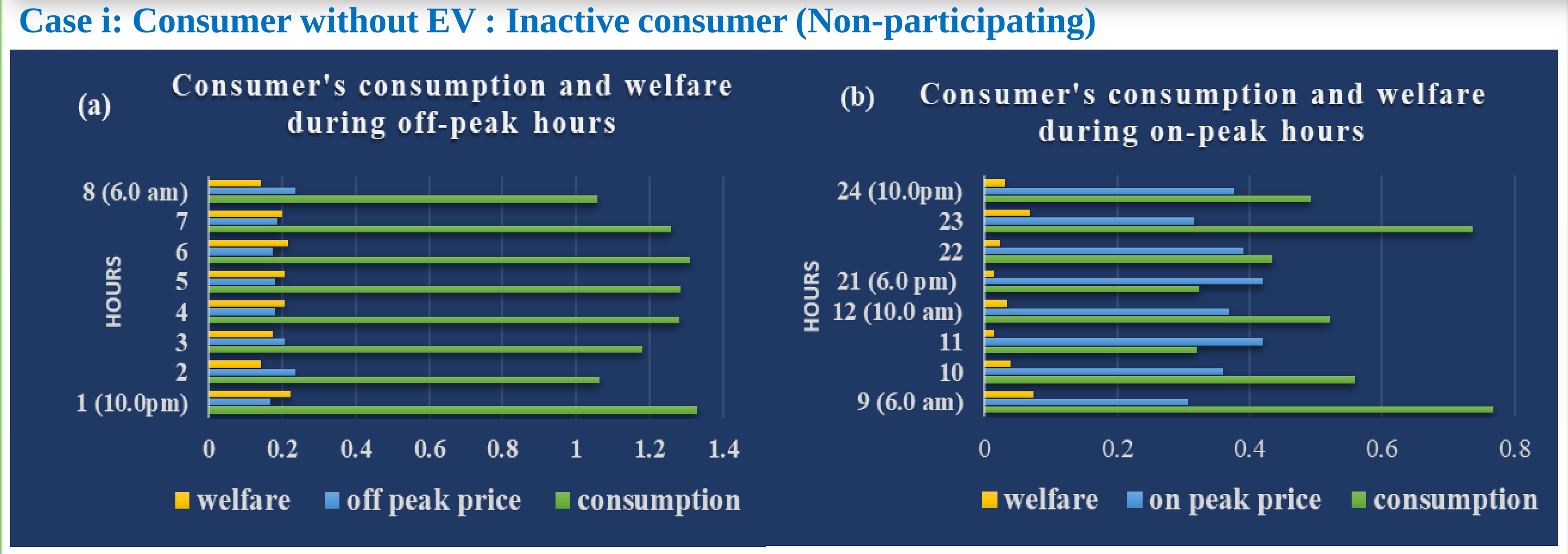

Fig.3.(a) Consumer's welfare and their consumption data w.r.t off-peak prices during off-peak hours (10.0pm-6.0 am), 3.(b) Change in consumer 's welfare and consumption data w.r.t on-peak prices during peak hours (6.0pm-10.0pm and 6.0 am to 10.0 am)

Case ii: Consumer with single EV: turning up as an EV-prosumer

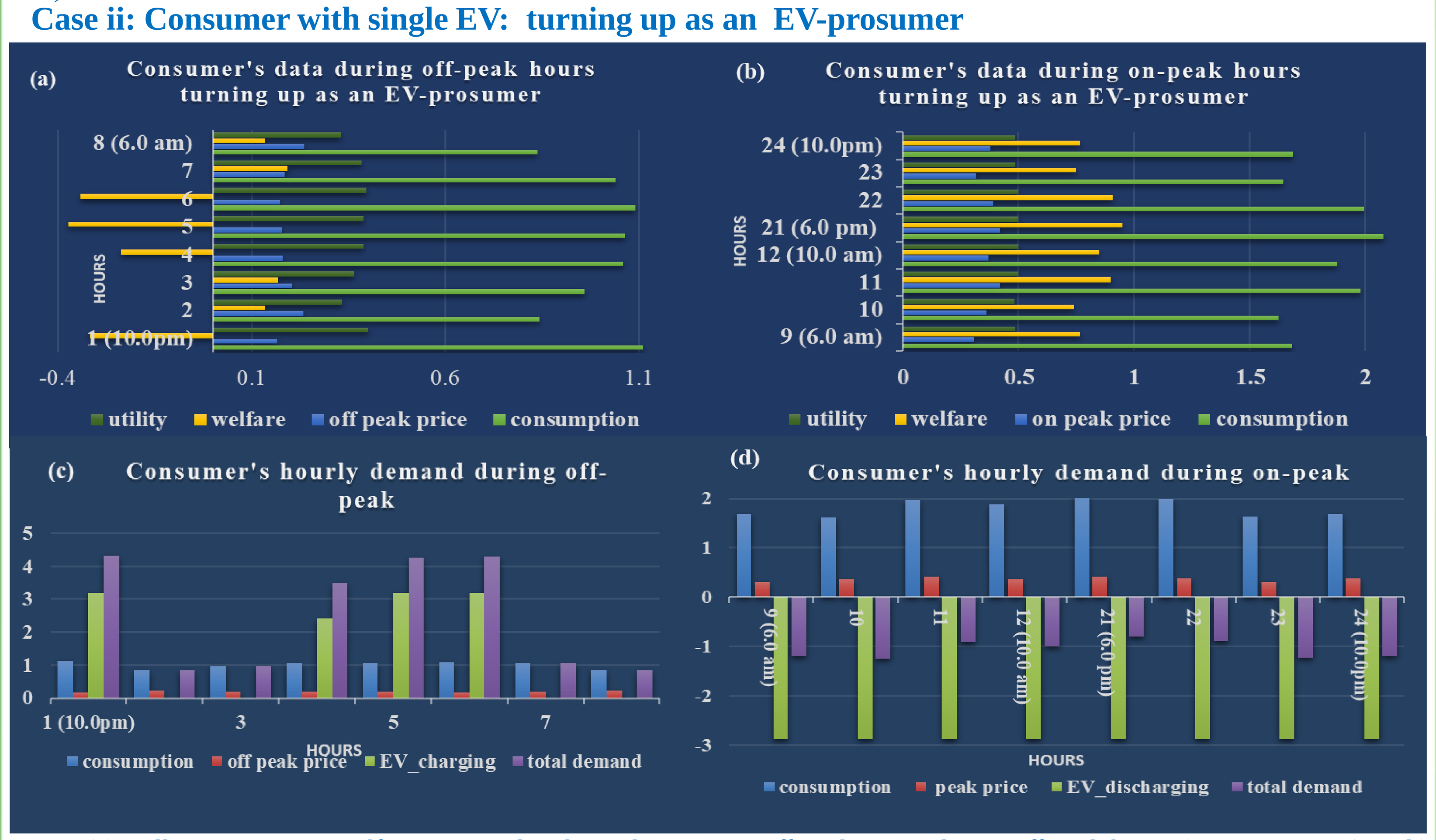

Fig. 4.(a) Fall in consumer's welfare equipped with single EVs w.r.t off-peak prices during off-peak hours (10.0pm-6.0 am), 4.(b) Significant increment in consumer 's welfare equipped with single EV w.r.t on-peak prices during peak hours (6.0pm-10.0pm and 6.0 am to 10.0 am), 4.(c) Increase in consumer's hourly demand with adoption of EV during off-peak hours, 4.(d) Decrease in consumer's hourly demand during on-peak hours

Case iii: Consumer with two ('2') EVs: Analysing change in revenue of an EV prosumer equipping with more than one EVs

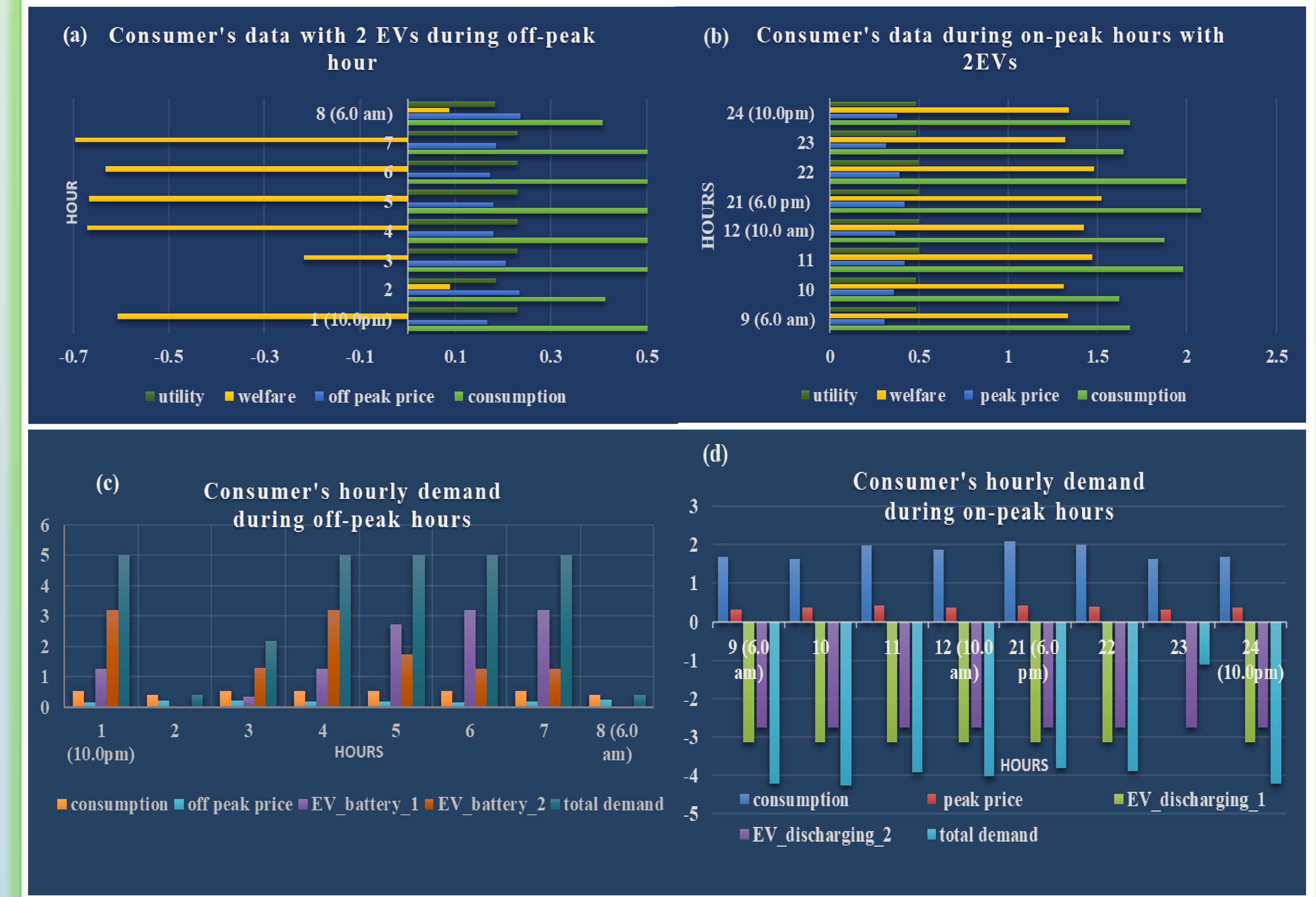

Fig. 5.(a) Fall in consumer's welfare equipped with two EVs w.r.t off-peak prices during off-peak hours (10.0pm-6.0 am), 5.(b) Increase in consumer 's welfare equipped with two EVs w.r.t on-peak prices during peak hours (6.0pm-10.0pm and 6.0 am to 10.0 am), 5.(c) Increase in consumer's hourly demand with 2 EVs during off-peak hours, 5.(d) Decrease in consumer's hourly demand during on-peak hours

Comparing the outcome of above three cases

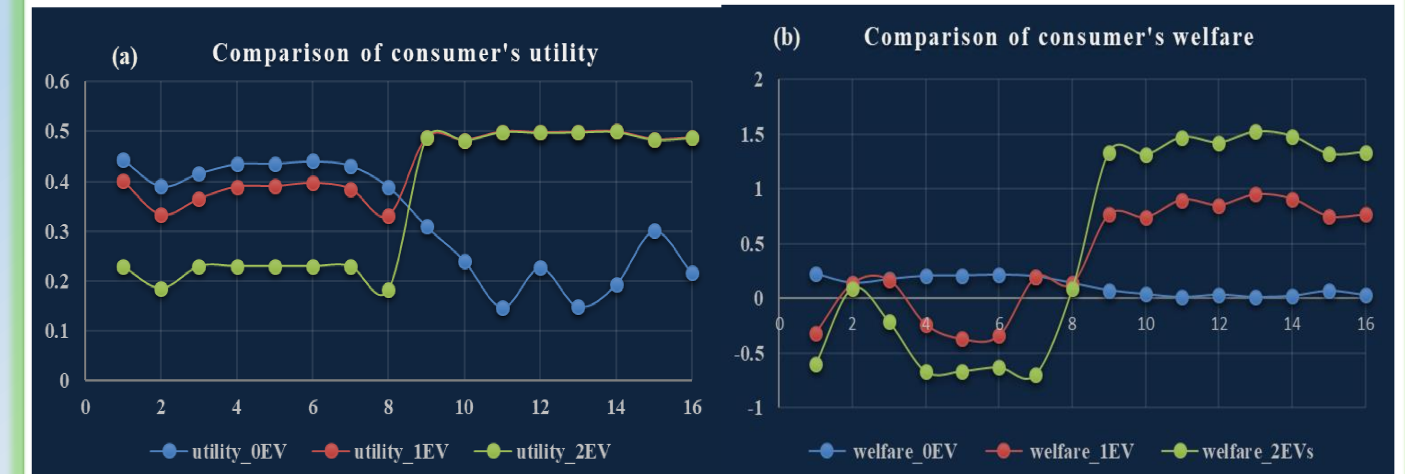

Fig. 6.(a) Changing in consumer's utility w.r.t off-peak (10.0pm-6.0 am) and on-peak (6.0pm-10.0pm and 6.0 am to 10.0 am) hours for 0,1, and 2 number of EVs 6.(b) Change in consumer 's welfare w.r.t off-peak (10.0pm-6.0 am) and on-peak (6.0pm-10.0pm and 6.0 am to 10.0 am)

Conclusions

- In this study, we present a model to empowers the inactive consumers as EV-prosumers under smart grid environment. The proposed model is based on consumer's welfare maximization.
- It shows a residential energy management with integration of electric vehicle as V2G/H, G2V and their impact on consumers welfare.
- A NLP is used to optimize the EV-prosumers 'payoff and self-consumption which shows the change in prosumer's self-consumption pattern (fig. 3 &4 (a, b)) with respect to inactive consumers.
- The simulation results reveals the highest incremental welfare for prosumer with 1 EV, however societal welfare is highest for 2 EVs.
- This means empowerment of an inactive consumer as an EV-prosumer maximize individual's payoff as well as have an optimistic effect on reducing GHGs.
- This study plays a significant role in mitigating the intention-action gap, self-knowledge and observable knowledge gap among consumers by illustrating the significance of impact of emergence of EV-prosumers.

References

1. Smart Grid Handbook for Regulators and Policy Makers | 1.
2. I. Malmgren, "Quantifying the societal benefits of electric vehicles," World Electr. Veh. J., vol. 8, no. 4, pp. 986–997, 2016.

Appendix: EV specific formulation

- **Basic modelling Equations:** MP= $-\tilde{\alpha} * \mathbb{Q} + \tilde{\beta}$; $\Pi(\mathbb{Q}) = MP * \mathbb{Q}$; $[\mathbb{Q}_{EV}^{T_{Peak}} = \left(\frac{\mathbb{Q}_{P3}^{T_{offPeak}}}{\sum_{EV} \chi_{EV}^{T_{offpeak}}}\right) * \sum_{EV} \Theta_{EV}^t]$
- **Emission equations:** $\mathbb{Q}_{EV}^{T_{Peak}} = \sigma * \sum_{EV} \Theta_{EV}^{T_{peak}}$; $\qquad \mathbb{Q}_{P3}^{T_{offPeak}} = \varepsilon * \sum_{EV} \chi_{EV}^{T_{offpeak}}$;
- $\chi_{EV}^{T_{offpeak}} = soc_{EV}(t+1) - soc_{EV}(t) \qquad (t \in T_{offpeak}) \qquad [\chi_{EV}$: battery charging]
- Note: $\{\mathbb{Q}_{P4}^{T_{Peak}} > \mathbb{Q}_{P3}^{T_{offPeak}} > (-\mathbb{Q}_{EV}^{T_{Peak}}) \,|\, \eta_{EV} > \eta_{P3} > \eta_{P4}\}$;
- [MP: market price of a commodity; $\tilde{\alpha}$ & $\tilde{\beta}$:coefficient; $\mathbb{Q}$: emission quantity; η: efficiency]