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Cost analysis of DCFC fast charging station power rates for workplace charging.

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Cost Analysis of DCFC Fast Charging Station Power Rates for Workplace Charging

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***Abstract*—DC fast charging (DCFC) station becomes prominent thanks to offering faster charging service. However, they increase the peak demand, hence, the demand charge for industrial and commercial customers increases. This study analyses cost behaviors of various DCFC power rates (i.e., 50 kW, 150 kW, 350 kW) at workplaces under demand metered and EV specific TOU rates for various EV utilization. An optimal cost model with proposed interrupted charging profile is presented that minimizes the daily levelized total cost of DCFC station at workplaces. It is shown that DCFC cost behaviors differ from the utility rate and EV utilization. From the grid perspective, the EV specific rate increases the peak demand considerably as compared to the demand metered rate. This is due to the nature of the TOU rate design. However, this impact can be minimized with solar generation that coincides with the peak demand hours.**

***Index Terms*—Demand charge, electrified fleets, EVSE, plug-in electric vehicles, time-of-use tariff, workplace charging.**

I. INTRODUCTION

Electrification of commercial fleets has taken place for reasons such as reduced emissions, economic benefits as well as energy diversity [1]. Charging infrastructure is one of enabling factors for scaling-up the electrified fleets as electric vehicle (EV) adoption and charging infrastructure deployment are linked. As such, availability of charging points at work and strategically located in urban areas can promote to this transition. At public car parks and on-street parking, DC fast charging (DCFC) station becomes prominent among the electric vehicle supply equipment (EVSE) configurations thanks to offering higher charging energy in shorter time enabling long-distance travel [2]. It is shown that enabling more public DCFC charging infrastructure drives higher EV adoption [3]. Although Level 2 or Mode 3 charging are typically installed at workplaces, DCFC could be an attractive option at workplaces as well when a multi-criteria decision-making is made that considers various parameters from technical, economical, and other social aspects [4]. Studies have shown that utility demand charge is the most significant cost factor affecting the DCFC station economics at workplaces [5]. It is found in [6] that demand charge can be significant portion of total electricity bill for even small commercial businesses. This will be particularly compounded as the DCFC power level increases from 50 kW to 350 kW in the next-generation DCFC stations.

The economics of DCFC stations can be linked with several factors such as EV utilization and utility rates [7]. The cost-effectiveness of DCFCs differs from the EV adoption levels. Due to higher capital costs, low EV adoption levels could make DCFCs unprofitable [8]. In this regard, adopting smart charging schemes could provide operators with efficient use of EVSE units [9]. Muratori et al. in [2] assess operational cost of public DCFC stations based on EVSE size and utilization rate including charging behavior. Preferential charging at off-peak hours and limiting multi-port EVSE units are proposed for cost mitigation. As this study considers only public DCFC stations, the capital costs are disregarded that could affect the overall cost behaviour significantly for DCFCs.

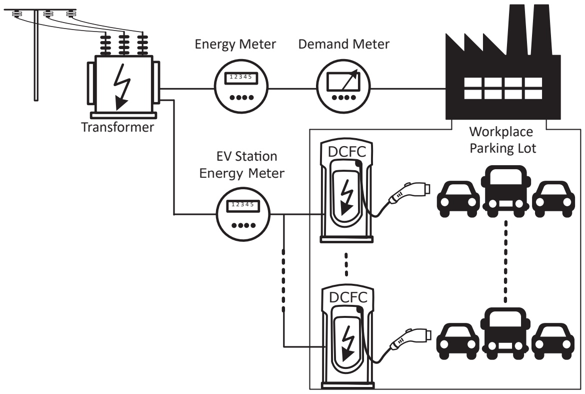

Fig. 1. Workplace electrical layout with general and EV specific meters.

To address demand charge barriers facing particularly DCFC site owners, several utilities including Pacific Gas and Electric (PG&E) and Southern California Edison (SCE) have put EV specific time-of-use (TOU) rates in place [10], [11]. While the proposed rates do not include demand charge, they include a monthly customer charge or subscription fee based on EV charging demand capacity. The EV charging demand is measured by a separate meter while maintaining the existing workplace energy and demand meters (Fig. 1). The idea behind these TOU tariffs is to shift the charging demand towards off-peak hours or periods of midday solar over-generation. It was shown in [12] that EV specific rates could achieve cost savings depending on charging strategy and EVSE configuration. However, the peak demand reduction with the proposed optimal planning approach is not always achievable. This is due to the elimination of demand charge in the objective function of the optimal model with EV specific rate that results in scheduling charging requests at the lowest

TOU rate periods in order to minimize charging cost only. This study considered the DCFC at 50 kW for a specific number of EVs. The behavior of DCFCs at different charging levels for various EV utilization rates is still unexplored.

As higher charging rates are becoming available in the deployment of next-generation DCFC stations, the main motivation of this study is to evaluate their cost behaviors based on EV utilization rate at workplaces. As such, the most cost-effective charging level can be identified for commercial and industrial sector when owning and operation of a charging infrastructure for transitioning their vehicles towards an electric fleet into the future. The impact of two different utility TOU rates (e.g., demand metered and EV specific rates) on cost behavior is also explored. The analysis is made through an optimal model whose objective is set to minimize overall cost of a workplace charging station. This comprises EVSE infrastructure and operational energy costs including utility demand and subscription charges. Three DC charging levels at 50 kW, 150 kW, and 350 kW for various EV numbers are considered in the analysis. The cost and grid behaviors of the charging levels under demand metered and EV specific utility rates are comparatively evaluated.

II. PRESENTATION OF DCFC STATIONS

DCFC or Mode 4 in IEC 61851 allows fast charging at a range of high DC power levels from 50 kW to 350 kW [2]. The charging rate can be limited depending on the EV's acceptance rate. Unlike AC EVSEs, DCFC includes a bidirectional high-power AC-DC converter with communication and control functions installed in. It is directly connected to the battery of EV rather than the on-board charger that requires a communication between DCFC unit and the battery management system of EV to start the charging process. DCFC infrastructure cost ranges from \$20,000 to \$150,000 as presented in [5] that is a result of an extensive analysis and survey. Three DCFC power rates presented are 50 kW, 150 kW, and 350 kW with cost ranges of \$20,000-\$35,800, \$75,600-\$100,00, and \$128,000-\$150,000, respectively. These costs exclude the transformer and cable costs. Moreover, DCFC installations at workplaces mostly require electrical upgrades and are subject to site factors including visibility and aesthetics that increase the installation cost significantly. EVSE costs are expected to have the same declining pattern as in solar sector and may result in lower costs in the future. In this study, the mean values of the cost ranges given above for the three DCFC power rates are used as EVSE infrastructure cost.

III. WORKPLACE CHARGING STATION COST MODEL

The cost model of a workplace charging station is the sum of capital (CAPEX) and operational costs (OPEX) (1). Daily levelized EVSE infrastructure cost, C_{EVSE} in (2), is considered as the CAPEX that includes EVSE unit hardware, C_{unit}, and installation and maintenance costs, C_{ins}. An annuity factor, AF, is considered to levelize the time value of money [13] for EVSE and its installation and maintenance costs for 15 years of lifetime with 5% interest rate. The second term, energy charge, C_{energy} in (3), is the OPEX accounting for daily total energy cost for charging EVs at workplace. The last term, demand or subscription charge, C_{demand} in (4), is also an OPEX representing utility demand charge or subscription cost depending on TOU rate considered. It refers to the contribution of EV charging loads to the peak demand of premises. C_{demand} is the product of the peak of demand in 15 min intervals (5) and either a demand rate, C_{drate} in (6) under PG&E B-19 tariff or a subscription charge $C_{subscription}$ in (6) under BEV-2 tariff. The subscription charge is depend upon blocks of charging demand. The objective function in (1) is formulated as a linear optimization problem that minimizes the daily total cost of DCFC over its lifetime as follows:

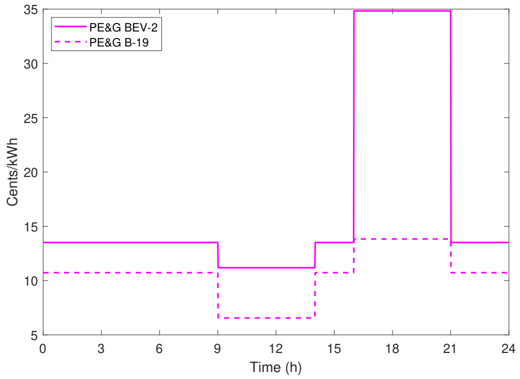

Fig. 2. Demand metered (B-19) and EV specific (BEV-2) TOU rates.

$$\min_{\substack{P_{ch,1}\dots P_{ch,n}\\ S_j}} \Big(C_{EVSE} + C_{energy} + C_{demand}\Big), \tag{1}$$

with,

$$C_{EVSE} = s_j \cdot AF \cdot \Big(C_{unit} + C_{ins}\Big), \tag{2}$$

$$C_{energy} = \sum_{s_j=1}^{s_j}\sum_{i=1}^{n}\sum_{t=1}^{T}\Big(\ F(t) \times (P_{ch,i,s_j}(t) \cdot \frac{\Delta t}{60})\Big), \tag{3}$$

$$C_{demand} = \begin{cases} C_{drate} \cdot P_{peak}, & \text{for} \quad \mathrm{B-19} \\ C_{subscription} \cdot P_{peak}, & \text{for} \quad \mathrm{BEV-2} \end{cases}, \tag{4}$$

where

$$P_{peak} = (max(\sum_{k=1}^{96}\sum_{t=1}^{15} mean(\sum_{1}^{s_j,n} P_{ch,i,s_j}((k-1)\cdot 15+t)))), \tag{5}$$

$$\begin{gathered} C_{drate} = \$22.77/kW, \\ C_{subscription} = \$95.86/50kW, \end{gathered} \tag{6}$$

subject to

$$\sum_{t=1}^{T} P_{ch,i}(t) \cdot \eta_i \cdot \frac{\Delta t}{60} = E_{required,i}, \tag{7}$$

$$\Big\{0 \leq P_{ch,i}(t) \leq \eta_J \cdot P_J^{rated}, \forall J \in \{1,2,3\}\Big\}, \tag{8}$$

$$\sum_{t=1}^{T}\Big(P_{base}(t) + \sum_{s_j=1}^{s_j}\sum_{i=1}^{n} P_{ch,i,s_j}(t)\Big) \leq P_{lim}, \tag{9}$$

TABLE I

IMPACT OF DCFC LEVELS ON THE UNIT COSTS UNDER DEMAND METERED AND EV SPECIFIC RATES WITH VARIOUS EV UTILIZATION.

Grid Tariff	**Charging Level**	**25 EVs**		**50 EVs**		**100 EVs**		**150 EVs**	
		Unit Cost [Cents/kWh]	EVSE No	Unit Cost [Cents/kWh]	EVSE No	Unit Cost [Cents/kWh]	EVSE No	Unit Cost [Cents/kWh]	EVSE No
Demand metered TOU	**50 kW**	23.2	2	22.4	2.95	21.3	4.58	21.0	6.25
	150 kW	31.9	1.22	31.0	2	27.1	2.92	24.8	3.39
	350 kW	38.5	1.11	40.8	1.94	30.9	2	27.1	2.46
EV specific rate	**50 kW**	21.7	1.9	22.1	2.42	22.3	3.95	22.3	5.11
	150 kW	27.4	1.01	26.4	1.84	22.4	2	24.0	2.81
	350 kW	38.7	1	25.2	1.01	24.6	1.91	21.0	2

where, $N = \{1, 2, ...n\}$, $P_{ch,i} = \{Pch, i(1)...Pch, i(T)\}$ are set of EVs and charging rates of the i^{th} EV, respectively. T is number of time slots, $S = \{1, 2, ...s\}$ is number of charging units. $J= \{1, 2, 3\}$ denotes charging levels of the DCFC units (i.e., 50 kW, 150 kW, and 350 kW). $F = \{f(1)...f(T)\}$ is the electricity pricing vector. P_J^{rated} and η_J are the rated power and the efficiency of DCFC unit, respectively.

Equation (7) ensures that the required energy for each EV ($E_{required,i}$) is supplied within arrival (t_{arr}) and departure times (t_{dept}) while (8) forces the EVSE charging level to be used, depending upon the DCFC power rating. The power limit on each plan imposed by the utility is satisfied by P_{lim} set to 1000 kW in (9).

A coordinated charging strategy is used for solving (1) while EV are scheduled by their arrival times. The strategy implements an smart charging with interrupted charging profile with idle times between plug-in and off times [14]. It is assumed that DCFC charging stations have multiple ports available for multiple cars, only one EV is charged at a time, and the arrival and departure times and the desired state-of-charge of the EVs are collected ahead of time by the station operator. The strategy uses a heuristic algorithm that maximizes utilization of the EVSE units, s. As such, EVs are placed into a charging unit sequentially. The available time slots and energy of the units are calculated considering the arrival and departure times of the EV and the charging powers of the previous EVs. If an incoming EV does not fit in the current unit, a new unit is added. The optimal charging scheduling is finalized using (1) for each arriving EV only.

IV. COST ANALYSIS

A. Description of TOU Rates Considered

In this study, a conventional demand metered TOU rate, PG&E B-19 [15], and EV specific TOU rate, PG&E BEV-2 [10], from the same utility are considered for DCFC cost analysis at workplaces. Fig. 2 compares the TOU rates used for energy charges in this analysis. Both tariffs are following the same time frames with peak, off-peak, and super-off peak hours. While the demand charge rate is \$22.77/kW in B-19 for aggregated load profile that is sum of demand of premises and total charging loads, the subscription charge in BEV-2 is \$95.86 per block of 50 kW for EVs charging demands. All the rates used in this study are for winter season.

B. Cost Analysis with Various EV Utilization Rates

A typical workplace EV charging data from a research institution is collected for comparative analysis. The data includes 5 different PEV types composed of (13.8 kWh, 3.7kW), (24kWh, 6.6kW), (30kWh, 6.6kW), (50kWh, 11kW), and (64kWh, 7.2kW) and equally distributed among a group of different number of EVs. The arrival and departure times and the required charging energy for EVs are assumed to be Gaussian. The efficiencies of the DCFC EVSE are considered as 97%. The SoC levels of EVs is assumed to be Gaussian with a mean of 0.45 and a standard deviation of 0.18. The EVSE types considered are all DCFC with power rates of 50 kW, 150 kW, and 350 kW. For each charging power, different EV utilization rates are considered (i.e., 25, 50, 100, and 150 EVs). Matlab optimization toolbox is used to develop and run the model with 1 min time interval for 100 times to include various randomly generated mobility cases. Results presented in tables and figures are the mean values of 100 trails. First-come, first-served charging schedule is employed in solving the optimization algorithm.

Table I presents the EV charging unit costs for each DCFC power rates under PG&E B-19 and BEV-2 tariffs. The unit cost refers to the ratio of daily total cost to total energy required to charge all EVs considered. Results show that the unit cost under the EV specific rate is lower compared to that of general demand metered rate for all DCFC power rates except at 50 kW for the number of 100 and 150 EVs, and at 350 kW for 25 EVs. This demonstrates that cost saving is possible with the EV specific rate over demand metered rate based on the mobility pattern considered. The unit cost under both rates mostly decreases as the EV utilization increases. The lowest unit cost is achieved by DCFC unit at 350 kW for the number of 150 EVs under the EV specific rate while the highest cost exists for the same EVSE unit under the demand metered TOU tariff for the lowest number of EVs (e.g., 25 EVs) considered. For the same EV utilization rates, the unit costs increase with DCFC power rates under both tariffs as the infrastructure costs increase. As expected, Table I also shows that the number of DCFC units increases in response to increased EV charging demand while it is decreased as the DCFC level increases. This indicates that the increase in EVSE cost is not linear with the power rates. Please note that the number of units are fractional due to the mean values of 100 different runs.

The cost breakdown of the total costs are given in Fig. 3

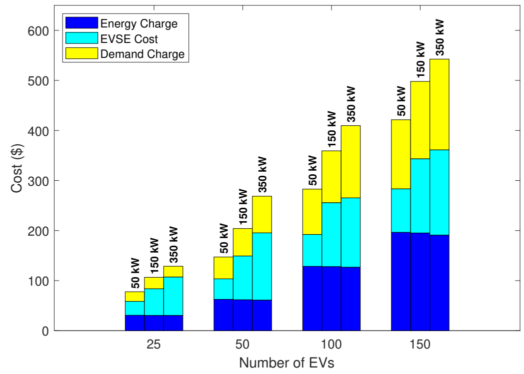

Fig. 3. Cost breakdown for DCFC levels under demand metered rate.

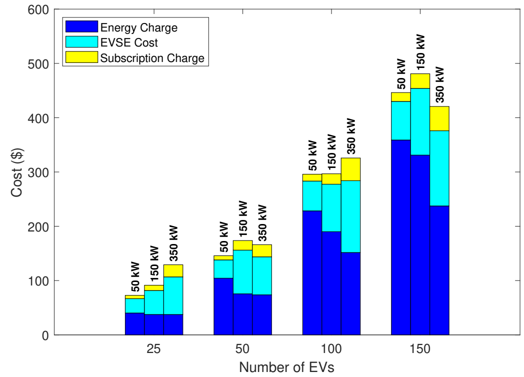

Fig. 4. Cost breakdown for DCFC levels under EV specific rate.

and 4. The total costs of the EV specific rates are found to be slightly lower for all utilization and power levels compared to that of the demand metered rates. The major difference between the two tariffs is observed in the demand charge. While the subscription charge is less compared to demand charge, the energy cost due to higher TOU rates of the EV specific rate in Fig. 2 compensates the difference. In both tariffs, the EVSE costs are found almost to be the same. As DCFC power rates increase, their cost behaviors under the demand metered rate remain the same irrespective of EV utilization rate. However, EV utilization rate affects considerably the cost behaviour under the EV specific rate.

It is observed under the demand metered rate in Fig. 3 that the EVSE cost is dominant at lower EV utilization (up to 50 EVs) for both 150 kW and 350 kW which constitute of more than half of the total cost (>50%). This is due to lower EV hosting capacities at higher charging power rates. On the other hand, the share of demand charge in total cost figure increases for higher EV utilization and charging power rates. The results confirm that the concerns on increase in demand charge for higher DCFC levels can easily exists under traditional demand metered rates. It is observed that DCFC power rates and EV utilization do not affect the energy charge behavior under the demand metered rate. However, the energy charge under the EV specific rate is highly affected by DCFC power rates (Fig. 4). As such, higher DCFC charging power reduces the energy charge due to the efficient use of lower TOU tariff periods.

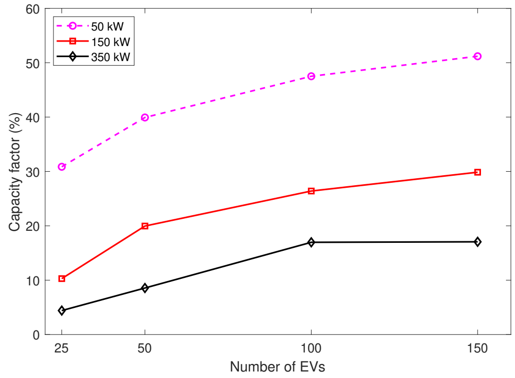

Fig. 5. Capacity factors of DCFC levels under demand metered rate

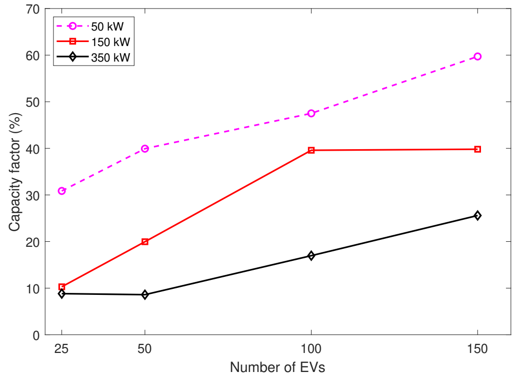

Fig. 6. Capacity factors of DCFC levels under EV specific rate.

It can be concluded that the cost behaviors of DCFC power rates are highly dependent on utility rate considered. Based on the mobility pattern, DCFC at 50 kW is found be the best economics under the demand metered rate irrespective of EV utilization rate. However, EV utilization rate affects the cost behavior under the EV specific rate. At lower EV utilization rates of up to 100 EVs, DCFC at 50 kW performs better while the higher charging power rate (e.g., 350 kW) becomes superior for higher EV utilization rates of more than 100 EVs.

The capacity factor (CF) is calculated for DCFC power rates. It is a measure of how many EVs can be hosted per EVSE unit that can be expressed by

$$CF(\%) = \frac{\sum_{i}^{n} E_{required}(i)}{S_j(i) \cdot \int_{min(tarr(1:n))}^{max(tdept(1:n))} (P_J^{rated} \cdot \eta_J) dt} \text{x100} \quad (10)$$

Fig. 5 and 6 present calculated CF values for various EV utilization. It is shown that the CF is higher at lower power levels under both tariffs considered. This is mainly due to the effective use of the lower charging power rates. The CF increases as the EV utilization increases that results in decrease in the unit cost as presented in Table I.

C. Impact on the Grid

The impact of the DCFC power rates on the grid is analyzed through the demand in 15 min intervals. Fig. 7 and 8 present

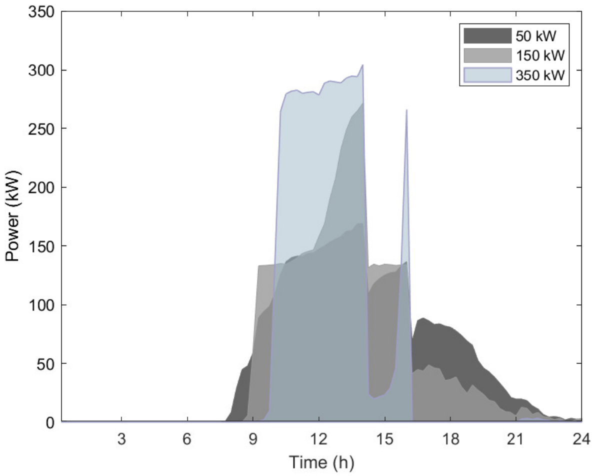

Fig. 7. Aggregated load profiles with 100 PEVs for demand metered rate

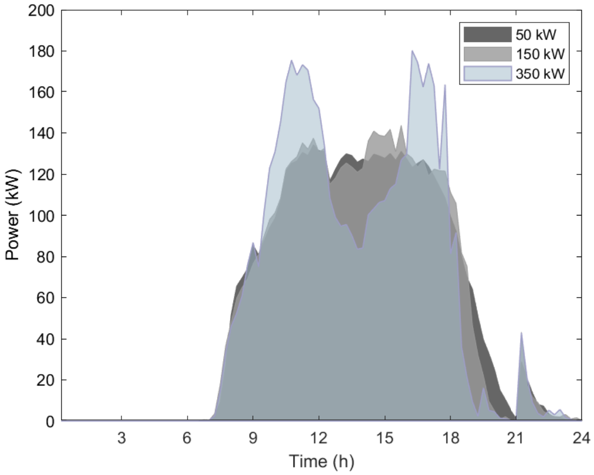

Fig. 8. Aggregated load profiles with 100 PEVs for EV specific rate.

total charging load profiles for three DCFC power rates for a utilization rate of 100 vehicles under both tariffs. The peak demands are found to be higher for the EV specific rate due to the lack of demand charge cost components in the objective function. The peak demand is 304.7 kW under BEV-2 while it is calculated to be 180.3 kW under the demand metered rate. Comparing the peaks for different charging rates, DCFC at 350 kW results in the highest peak under both tariffs. The difference in peak among the charging rates is less significant under the demand metered tariff. This concludes that while the EV specific rate provides cost saving for the EV user, the peak demand increases on the grid side. This increase becomes even more significant at higher DCFC power levels. As the peak demand occurs at the midday hours that is a result of the EV specific TOU rate, the peak demand can therefore be used to balance over solar generation. Hence, the impact on the grid can be reduced.

V. CONCLUSIONS

The followings can be concluded from the analysis:

- From the station owner perspective, cost saving is possible with the EV specific rate over demand metered rate based on the mobility pattern considered.
- In terms of the grid perspective, the EV specific rate cause higher peak demand compared to that of demand metered rate. However, the peak occurs at the super off-peak period that coincide with the highest solar generation period. Therefore, the peak can be used to balance the over solar generation.
- EV utilization has no impact on the cost behaviour under demand metered tariff. DCFCs with low power rates (e.i, 50 kW) is always the most cost effective EVSE option for various EV utilization rates. However, EV utilization affects significantly the cost behaviour under the EV specific tariff.

While various DCFC power rates provide economic benefits under different tariffs and EV utilization rates, a detailed analysis is needed based on the mobility pattern of fleet. It must be noted that most of available EVs on the market limits their maximum fast charging power. DCFC at lower power rates might become a better option for the fleet owners.

REFERENCES

[1] Global EV outlook: Scaling-up the transition to electric mobility. https://https://www.iea.org/reports/global-ev-outlook-2019. [Online; accessed 01-Dec-2020].

[2] M. Muratori, E. Kontou, and J. Eichman, "Electricity rates for electric vehicle direct current fast charging in the united states," *Renewable and Sustainable Energy Reviews*, vol. 113, p. 109235, 2019.

[3] S. Li, L. Tong, J. Xing, and Y. Zhou, "The market for electric vehicles: indirect network effects and policy design," *Journal of the Assoc. of Env. and Resource Economists*, vol. 4, no. 1, pp. 89–133, 2017.

[4] N. Erdogan, D. Pamucar, S. Kucuksari, and M. Deveci, "An integrated multi-objective optimization and multi-criteria decision-making model for optimal planning of workplace charging stations," *Applied Energy*, vol. 304, p. 117866, 2021.

[5] C. N. Garrett Fitzgerald, "Evgo fleet and tariff analysis phase-1 california," https://www.rmi.org, Tech. Rep., 2017, [Online; 01-June-2021].

[6] Z. J. Lee, J. Z. Pang, and S. H. Low, "Pricing ev charging service with demand charge," *Electric Power Sys Research*, vol. 189, p. 106694, 2020.

[7] D. McFarlane, M. Prorok, B. Jordan, and T. Kemabonta, "Overcoming barriers to expanding fast charging infrastructure in the midcontinent region," Tech. Rep., 2019, [Online; 01-June-2020].

[8] L. Zhang, "Electricity pricing in a partial reformed plan system: The case of china," *Energy Policy*, vol. 43, pp. 214–225, 2012.

[9] F. Erden, M. C. Kisacikoglu, and N. Erdogan, "Adaptive v2g peak shaving and smart charging control for grid integration of pevs," *Electric Power Components and Systems*, vol. 46, no. 13, pp. 1494–1508, 2018.

[10] P. Gas and E. Company. (October 1, 2020) Electric schedule BEV (business electric vehicle). [Online]. Available: https://www.pge.com/en_US/small-medium-business/energy-alternatives/clean-vehicles/ev-charge-network/electric-vehicle-rate-plans.page/

[11] S. C. Edison. (March 1, 2019) Electric vehicle rates for businesses. [Online]. Available: https://www.sce.com/business/rates/electric-car-business-rates/business/rates/electric-car-business-rates

[12] S. Kucuksari and N. Erdogan, ""EV specific time-of-use rates analysis for workplace charging"," in *2021 IEEE Transportation Electrification Conference & Expo (ITEC)*. IEEE, 2021, pp. 783–788.

[13] Y. Huang and Y. Zhou, "An optimization framework for workplace charging strategies," *Transportation Research Part C: Emerging Technologies*, vol. 52, pp. 144–155, 2015. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0968090X15000303

[14] A. Malhotra, N. Erdogan, G. Binetti, I. D. Schizas, and A. Davoudi, "Impact of charging interruptions in coordinated electric vehicle charging," in *2016 IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, 2016, pp. 901–905.

[15] P. Gas and E. Company. (February, 2021) Medium general demand-metered service. [Online]. Available: https://www.pge.com/tariffs/index.page