A Smart Dynamic Pricing Approach for Electric Vehicle Charging in a Distribution System

Ozan Erdinç, Ayse Kübra Erenoğlu
Department of Electrical Engineering
Yildiz Technical University
İstanbul, Turkey
e-mail: {oerdinc, erenayse}@yildiz.edu.tr

İbrahim Şengör
Electrical and Electronics Engineering Department
İzmir Katip Çelebi University
İzmir, Turkey
e-mail: ibrahim.sengor@ikcu.edu.tr

İbrahim Can Taştan, Ali Fuat Büyük
Smart Systems, R&D
Osmangazi Electricity Distribution Co.
Eskişehir, Turkey
e-mail: {ibrahim.tastan, ali.buyuk}@oedas.com.tr

João P.S. Catalão
Faculty of Engineering of the University of Porto and
INESC TEC,
Porto, Portugal
e-mail: catalao@fe.up.pt

2020 9th International Conference on Power Science and Engineering (ICPSE) | 978-1-7281-8453-1/20/$31.00 ©2020 IEEE | DOI: 10.1109/ICPSE51196.2020.9354365

***Abstract*—Transportation electrification has become a prominent area of research and investment, especially in the last decades, regarding the increasing concerns for environmental sustainability. In this manner, there are different studies realized on electric vehicles (EVs), especially from the power system integration point of view to enable a more extensive penetration without causing adverse impacts on system operation. Different approaches for the direct and indirect management of EVs based charging demand in power systems have already been proposed in the literature as well as employed in the industry. In this study, from an indirect management point of view, a smart dynamic pricing approach based on a fuzzy logic controller based decision-making structure is proposed for EV charging in a distribution system. The proposed new decision-making method considers dynamically varying as well as static operational issues together with the social welfare of EV owners to provide real-time decisions compared to existing studies considering the wider EV charging service pricing topic from a different perspective.**

Keywords—charging station; distribution system; dynamic pricing; electric vehicles; fuzzy logic; smart decision making

I. Introduction

A. Motivation and Background

Environmental awareness increasing gradually during the last decades has provoked vital changes in different industries. Among them, the transportation industry responsible for a vital portion of greenhouse gas emissions in the world due to its pivotal position in oil consumption is one of the leading industries keeping pace with these changes, especially with the electrification attempts. In this manner, electric vehicles (EVs) have become a topic of significant research and investments in the world lately, where the EVs on the roads worldwide has reached a number of over 5.1 million in 2018 [1].

Even the EVs have many advantageous points, especially regarding environmental benefits compared to the fossil-fueled transportation industry, there are also significant barriers to overcome for more effective competition with conventional rivals. The range anxiety, as well as battery aging, can be considered among the in-vehicle problems for sole battery EVs while the planning, commissioning, and operating the relevant charging infrastructure to supply EVs' demand pertain to the power system related problematic issues.

As a more specific topic in this manner, several approaches exist for the active management of the charging demand of EVs within the distribution system. The mentioned active management approaches can be classified as direct and indirect methods. The strategies in which the EV charging stations are managed directly by the distribution system operators or the aggregators (as a medium) form the direct methods. The studies in this area constitute the majority of the existing literature and industrial applications. On the other hand, the indirect approaches are based on the management of EV charging service via a dynamic pricing concept considering different operational issues. The mentioned pricing based indirect management approaches have drawn increasing interest in recent years.

B. Relevant Background

There are several studies in the literature considering the pricing based indirect EV charging demand management issue. Among them, optimal pricing scheme determination oriented studies comprise the most considerable portion in this manner. Li et al. [2] considered the EV charging management problem from an optimal locational marginal pricing (LMP) determination point of view where EV aggregators were discussed in a price taker position in distribution system operation with social surplus maximization objective. Another decentralized EV aggregator based study for distribution system operator and EV owner interaction was proposed by Xi and Sioshansi in [3], where the distribution system operator and the EV aggregator had conflicting objectives during the definition of optimal price signals. A chance-constrained Mixed-Integer

Authorized licensed use limited to: b-on: UNIVERSIDADE DO PORTO. Downloaded on February 18,2021 at 19:14:25 UTC from IEEE Xplore. Restrictions apply.

Programming framework based model for optimal EV charging LMP decisions tackling with also the EVs based uncertainties was proposed by Liu et al. [4] in a dual side concept, where the EV aggregator and the distribution system operator respectively aimed to minimize the EV charging and total electricity consumption costs.

A cost-minimization oriented optimization problem was formulated in [5] for a multi-region EV day ahead charging scheduling via distributed charging pricing. Another optimal pricing, as well as scheduling approach for EV charging specifically for EV sharing business model, was deployed in [6]. Besides, the multi-region pricing concept via a self-adaptive mechanism was also provided for a smart city in [7]. A dual step approach to determine the optimal price settings for EV charging was proposed by Soltani et al. in [8] to benefit from the price elasticity of EV owners. The study in [8] was initiated with capturing the price responsiveness of EV demand by a conditional random field model where then the obtained model parameters were supplied as an input to a profit maximization oriented stochastic optimal price-setting model. The price elasticity of EV charging service was also considered in [9] from a service dropping minimization point of view.

A game theoretic approach for EV charging service pricing was proposed by Yuan et al. [10] for the interaction between the charging stations and EVs with conflicting targets. In [10], each charging station was aimed to maximize its profit by determining the optimal charging service price with the forecast of charging station selection of EVs, and the mentioned decision of EVs was on the other hand considered based on different charging stations' competitive price signals, waiting times and travel distances. Another location aware pricing integrated game theoretic approach based study can also be found in [11]. The EV charging station pricing competition was also considered in another study [12], where a heterogeneous distribution for charging stations was considered.

A cooperative operation of power and transportation networks where the combined objectives considered the minimization of travel times to reach the charging station (also taking the traffic conditions into account) as well as the congestion in the power system was proposed in [13]. Other power and transportation network coupling concepts were also introduced in [14]-[16]. The determination of optimal charging prices for EVs in parking lots equipped with distributed generation and energy storage units considering the distribution system constraints imposed by the system operator was proposed by Awad et al. in [17].

A collective charging load management of EV taxi fleets through a real-time pricing approach was considered in [18]. A dynamic pricing approach dedicated to EV extreme fast charging, also considering the traffic conditions between the EV location and the charging points, was proposed in [19]. An EV charging pricing scheme for the peer-to-peer operating possibility of distributed generation equipped commercial end-users and EV charging stations was presented in [20] with relevant comparisons from the prosumer total cost, distributed generation self-consumption and prosumer participation willingness points of view. A real-time pricing and scheduling approach based on reinforcement learning for EV charging service was persuaded in [21]. Another interesting study to decide dynamic prices for EV charging via a rule-based heuristic approach for real-time implementation was proposed in a recent study [22]. The bi-directional utilization based concept for EV grid interaction management considering vehicle-to-X (V2X) possibility apart from solely coordinating the EV charging was also evaluated in numerous studies such as [23]-[28].

A detailed survey on the use of smart approaches based on artificial intelligence for the management of EV demand in smarter power networks was presented by Rigas et al. [29], where a specific subpart was also devoted to EV charging demand pricing schemes. There are also numerous more studies in the literature that cannot all be referred here, which have contributed to the knowledge on the use of pricing based indirect EV management for enhanced system operation. However, even the use of smart approaches enabling a real-time implementation possibility for EV charging service pricing is gaining increasing interest; there is not a sufficient number of studies dealing with such approaches considering simultaneously the power system operation based technical as well as EV owner oriented social points of such decision-making procedures.

C. *Contribution and Paper Organization*

In this study, a fuzzy logic controller based smart dynamic pricing approach for EV charging service is proposed from the distribution system operator point of view. The proposed smart decision-making approach considers the static and dynamically varying distribution system operational conditions as well as the social concept of the problem via rewarding the reduction of the energy consumption of EVs in demand of charging while reaching the charging station as inputs. Accordingly, the proposed approach decides the dynamically varying price multipliers that can further be turned into real prices to convey the EV owners. The performance of the proposed method is tested under realistic conditions of a distribution system. Herein, the main contributions of the proposed study can be summarized as follows:

- The consideration of dual technical and social sides of the pricing problem is realized using a smart real-time decision-making approach.
- The differentiation of pricing schemes among different buses and charge demanding EVs is realized to enable a highly flexible indirect EV charging management possibility.

The rest of this paper is organized as follows: Section II indicates the details regarding the methodology of the proposed model. Section III describes the evaluated distribution system with the relevant input data. Moreover, the simulation results are discussed in this section. Finally, concluding remarks of the study are highlighted in Section IV.

II. METHODOLOGY

The application concept of the general decision-making mechanism is depicted in Fig. 1. Herein, firstly the EV

Authorized licensed use limited to: b-on: UNIVERSIDADE DO PORTO. Downloaded on February 18,2021 at 19:14:25 UTC from IEEE Xplore. Restrictions apply.

owner easily conveys the charging demand, also mentioning the current charge status to the system operator via a smartphone application. Accordingly, a set of reachable (in-range) charging stations is provided for the mentioned EV by calculating the approximate range that the EV can reach with the current charge status and then considering the distance between the location of the EV and charging stations. Afterward, the set of in-range charging stations is reduced to a subset of available in-range charging stations considering the service status (either on duty or reserved for charging service dedicated to another EV) of the mentioned charging station. Then, a price multiplier is provided for each of the available in-range charging stations and each EV by the fuzzy logic controller based decision-making mechanism. The mentioned price multiplier can be accordingly used by the system operator to determine the real charging prices by multiplying them with any determined varying or constant base price. As the mentioned last stage after the determination of price multipliers includes the energy market integration, service costs, management policy, etc. issues, the mentioned final part is naturally out of the scope of this study. Besides, a similar sample concept for the mentioned smartphone application and the relevant other procedures can also be exemplified in the previous studies of the Authors in [30] and [31].

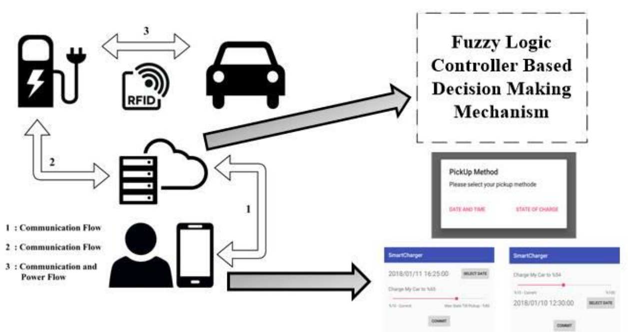

Figure 1. The application concept of the general decision making mechanism.

As mentioned above, the smart dynamic pricing mechanism is based on fuzzy logic controller approach, which is a vitally effective method widely used in several industrial applications and academic studies since initially proposed by Lotfi Zadeh in the 1970s. Unlike Boolean Algebra defining the decisions either as 1 or 0, fuzzy logic also describes the partial membership conditions to different system states, enabling a closer behavior to the real-time human decision making procedure. The independence from a full mathematical model of the process to make a decision via exploiting from the expertise of the designer on the procedure makes the fuzzy logic approach a very powerful tool to use, especially in real-time highly complex decision-making procedures.

The mentioned fuzzy logic controller based pricing mechanism is depicted with the block diagram given in Fig. 2. As seen, the decision-making mechanism considers the relative bus distance, normalized bus loading, and relative time distance information as inputs to determine the relevant price multiplier for each EV demanding charging service and for each available in-range charging station. The rule base for the mentioned concept is depicted in Table I while the relevant decision surface for two sample inputs, and the output is given in Fig. 3 as an example where the mentioned surface is identical for all combinations of any two inputs and the output.

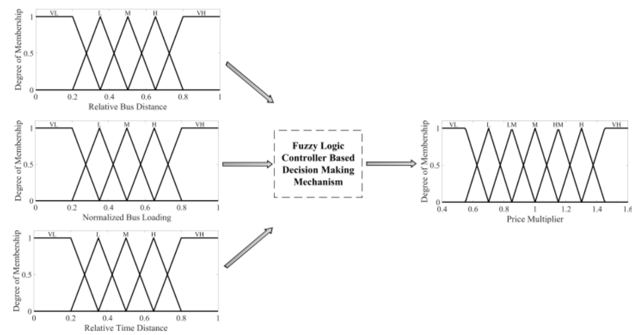

Figure 2. The block diagram of the fuzzy logic controller based decision making mechanism.

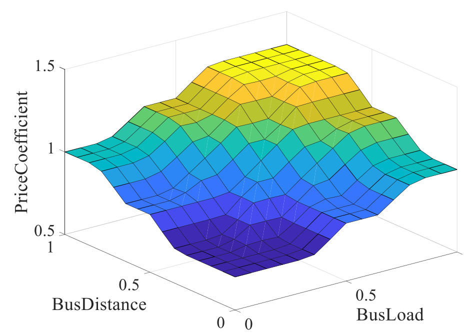

Figure 3. A sample decision surface for the fuzzy logic controller based decision making mechanism.

Herein, the relative bus distance corresponds to the normalized value obtained via dividing the distance of each charging station integrated bus to the main substation by the similar distance magnitude of the bus with the greatest distance to the main substation. The consideration of this input depends on the logic of incentivizing the buses leading to lower losses due to the direct proportion of the losses caused by a load in any bus with the distance of the relevant bus from the main supply point. As the second input of the fuzzy logic controller based smart pricing approach, the nominal transformer loading values are obtained by dividing the loading of the buses during the decision making time by the nominal bus power. The consideration of this issue relies on the mentality of incentivizing the less loaded busses during pricing decisions. As the final input of the smart pricing mechanism, the relative time distance is obtained via dividing the reaching time of an EV to any available in-range charging stations by the highest time among the time set composed of the reaching times to all charging stations. Herein, the mentioned reaching times are affected by the dynamic conditions such as the distance between the EV and the available in-range charging stations as well as the traffic conditions and these reaching times can easily be obtained

Authorized licensed use limited to: b-on: UNIVERSIDADE DO PORTO. Downloaded on February 18,2021 at 19:14:25 UTC from IEEE Xplore. Restrictions apply.

using a navigation application (such as Google Maps) operated at the background of the decision-making mechanism. The mentioned final input is in the scope of the social responsibility of the system operator gaining increased importance recently rather than technical operating conditions and relies on the principle of providing price advantage for the nearer charging stations those can reduce the energy consumption during the process of the EV to reach the charging station.

Such comfort, savings, etc. improvement based end-user oriented approaches are considered vital in different applications in the world to enhance the participation of end-users to such demand manipulation oriented programs. Considering these three inputs, the price multiplier under dynamic conditions is determined special to each EV and bus pair via the relevant decision-making mechanism.

III. Test and Results

The method propounded for pricing of EV charging service within a distribution system has been tested using the model of a real distribution system portion managed by Osmangazi Electricity Distribution Company (OEDAŞ). Figure 4 shows the single line diagram of the evaluated distribution system model.

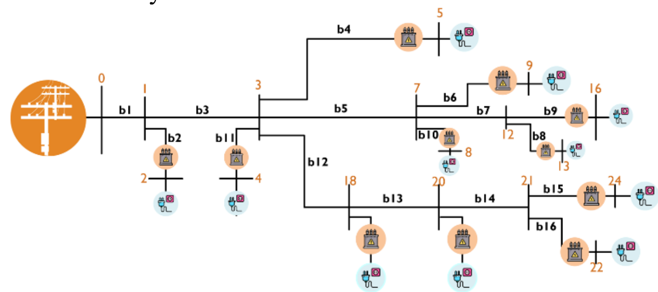

Figure 4. Single line diagram of the evaluated distribution system.

TABLE I. Fuzzy Logic Controller Rule Base

R	I1	I2	I3	O	R	I1	I2	I3	O	R	I1	I2	I3	O	R	I1	I2	I3	O	R	I1	I2	I3	O
1	VL	VL	VL	VL	*26*	L	VL	VL	VL	*51*	M	VL	VL	L	*76*	H	VL	VL	L	*101*	VH	VL	VL	LM
2	VL	VL	L	VL	*27*	L	VL	L	L	*52*	M	VL	L	L	*77*	H	VL	L	LM	*102*	VH	VL	L	LM
3	VL	VL	M	L	*28*	L	VL	M	L	*53*	M	VL	M	LM	*78*	H	VL	M	LM	*103*	VH	VL	M	M
4	VL	VL	H	L	*29*	L	VL	H	LM	*54*	M	VL	H	LM	*79*	H	VL	H	M	*104*	VH	VL	H	HM
5	VL	VL	VH	LM	*30*	L	VL	VH	LM	*55*	M	VL	VH	M	*80*	H	VL	VH	HM	*105*	VH	VL	VH	HM
6	VL	L	VL	VL	*31*	L	L	VL	L	*56*	M	L	VL	L	*81*	H	L	VL	LM	*106*	VH	L	VL	LM
7	VL	L	L	L	*32*	L	L	L	L	*57*	M	L	L	LM	*82*	H	L	L	LM	*107*	VH	L	L	M
8	VL	L	M	L	*33*	L	L	M	LM	*58*	M	L	M	LM	*83*	H	L	M	M	*108*	VH	L	M	HM
9	VL	L	H	LM	*34*	L	L	H	LM	*59*	M	L	H	M	*84*	H	L	H	HM	*109*	VH	L	H	HM
10	VL	L	VH	LM	*35*	L	L	VH	M	*60*	M	L	VH	HM	*85*	H	L	VH	HM	*110*	VH	L	VH	H
11	VL	M	VL	L	*36*	L	M	VL	L	*61*	M	M	VL	LM	*86*	H	M	VL	LM	*111*	VH	M	VL	M
12	VL	M	L	L	*37*	L	M	L	LM	*62*	M	M	L	LM	*87*	H	M	L	M	*112*	VH	M	L	HM
13	VL	M	M	LM	*38*	L	M	M	LM	*63*	M	M	M	M	*88*	H	M	M	HM	*113*	VH	M	M	HM
14	VL	M	H	LM	*39*	L	M	H	M	*64*	M	M	H	HM	*89*	H	M	H	HM	*114*	VH	M	H	H
15	VL	M	VH	M	*40*	L	M	VH	HM	*65*	M	M	VH	HM	*90*	H	M	VH	H	*115*	VH	M	VH	H
16	VL	H	VL	L	*41*	L	H	VL	LM	*66*	M	H	VL	LM	*91*	H	H	VL	M	*116*	VH	H	VL	HM
17	VL	H	L	LM	*42*	L	H	L	LM	*67*	M	H	L	M	*92*	H	H	L	HM	*117*	VH	H	L	HM
18	VL	H	M	LM	*43*	L	H	M	M	*68*	M	H	M	HM	*93*	H	H	M	HM	*118*	VH	H	M	H
19	VL	H	H	M	*44*	L	H	H	HM	*69*	M	H	H	HM	*94*	H	H	H	H	*119*	VH	H	H	H
20	VL	H	VH	HM	*45*	L	H	VH	HM	*70*	M	H	VH	H	*95*	H	H	VH	H	*120*	VH	H	VH	VH
21	VL	VH	VL	LM	*46*	L	VH	VL	LM	*71*	M	VH	VL	M	*96*	H	VH	VL	HM	*121*	VH	VH	VL	HM
22	VL	VH	L	LM	*47*	L	VH	L	M	*72*	M	VH	L	HM	*97*	H	VH	L	HM	*122*	VH	VH	L	H
23	VL	VH	M	M	*48*	L	VH	M	HM	*73*	M	VH	M	HM	*98*	H	VH	M	H	*123*	VH	VH	M	H
24	VL	VH	H	HM	*49*	L	VH	H	HM	*74*	M	VH	H	H	*99*	H	VH	H	H	*124*	VH	VH	H	VH
25	VL	VH	VH	HM	*50*	L	VH	VH	H	*75*	M	VH	VH	H	*100*	H	VH	VH	VH	*125*	VH	VH	VH	VH

*R: Rules, I1: Input-1, I2: Input-2, I3: Input-3, O: Output, VL: Very Low, L: Low, LM: Low Medium, M: Medium, HM: High Medium, H: High, VH: Very High

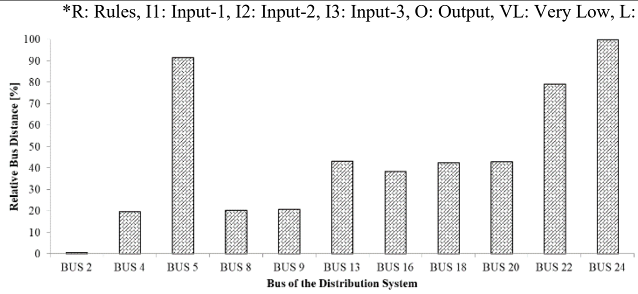

Figure 5. Relative distance values for different buses.

As can be seen in the demonstration, it is a radial type 24-bus network with eleven of the 24-bus are equipped with a transformer. The percentage of relative bus distances for the buses equipped with charging stations within the relevant distribution system region is portrayed in Fig. 5. Similarly, the percentage of bus loading values is also depicted in Fig. 6. Herein, a test regarding three EVs conveying their charging requests from different locations of the distribution system is realized. Among the mentioned EVs, EV-1 is located at Bus-12 while EV-2 and EV-3 demand charging respectively from Bus-21 and Bus-1. For the sake of simplicity, it is assumed here that all the charging stations in all buses of the sample distribution system region are within the range of all EVs considering their charge levels and each bus includes at least one available charging station to possibly reserve by each of the mentioned EVs. In this manner, the relative time distance values to charging station equipped buses are shown in Figs.

Authorized licensed use limited to: b-on: UNIVERSIDADE DO PORTO. Downloaded on February 18,2021 at 19:14:25 UTC from IEEE Xplore. Restrictions apply.

7-9 respectively for EV-1, EV-2 and EV-3. As a navigation application is not operated behind the decision making approach in the current version of the study and the mentioned distribution system region includes negligible amount of traffic in real conditions, it should here be noted that the real distances between the EV locations and the distribution system buses are utilized for the calculation of the mentioned relative time distances in order to obtain an acceptable level of convergence in this case study.

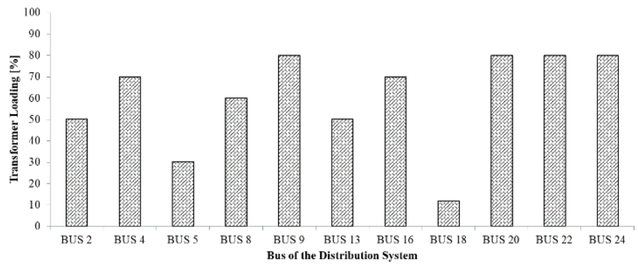

Figure 6. Transformer loading levels for different buses.

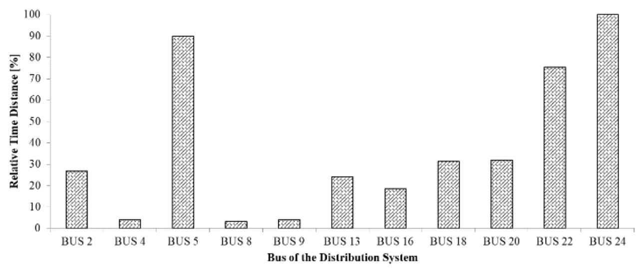

Figure 7. Relative time distance values to different buses for EV-1.

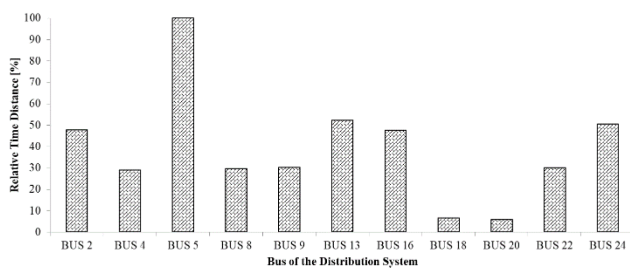

Figure 8. Relative time distance values to different buses for EV-2.

The price multipliers determined by the fuzzy logic controller based decision making mechanism for each EV and each bus under aforementioned operating conditions are depicted in a summarized way within Fig. 10. Firstly, it can be observed that the price multipliers are not identical for different EVs in distribution system buses. This issue shows importance specifically in order to incentivize the routing of EV owners to nearer buses those can be reached with lower energy consumption. Herein, the social responsibility output is obtained via lowering the energy consumption of each EV while reaching the relevant charging station and therefore reducing the indirect impact of the cumulative summation of the consumptions during these conditions without the objective of a real journey on several issues such as energy economy, emissions, distribution system operation (due to the fact that energy consumptions increase the charging demand either from power or time points of view), etc. Besides, it can also be seen from Fig. 10 that the price multipliers decided for each EV also differ between buses and price multipliers even below 0.6 or above 1.4 occur.

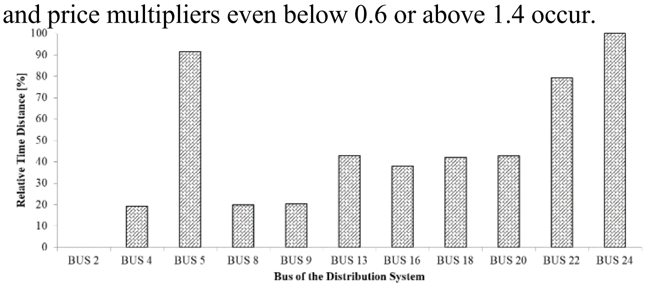

Figure 9. Relative time distance values to different buses for EV-3.

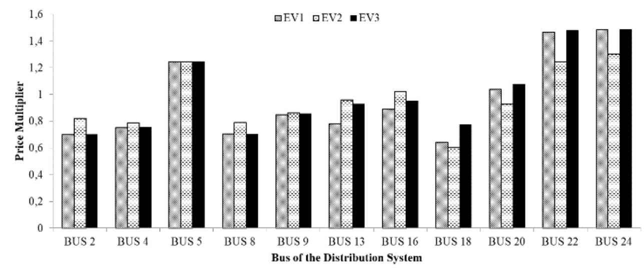

Figure 10. Determined price multiplier values for different buses regarding charging of different EVs.

The price multipliers are manipulated sensitively under different EV locations and varying bus loading conditions via the mentioned real-time smart decision making approach. This issue clearly figures out that the relevant decision making mechanism effectively capture the variations of system operating conditions in a dynamic manner in order to present the applicability of the proposed approach with possibly required modifications.

IV. Conclusion

The role of EVs in the transportation industry has recently experienced a rapid increase and is expected to grow more vitally in the upcoming decade. The active coordination of charging demand of the EVs has a specific importance in this manner for a wider adoption to an electrified transportation. In this study, a smart real-time pricing strategy for EV charging service in a distribution system was proposed. The mentioned strategy depends on a fuzzy logic controller based decision making mechanism. The tests conducted using a real distribution system portion data revealed the sensitivity of the proposed approach to the different distribution system related operating conditions as well as status of the EV owners demanding charging service.

The outcomes of the decision making mechanism can be enabled to use in real applications via indicating the price of the least costly charging station (or demanding to select at most one option among different charging station options with the information of price and time to reach) to the EV owner via a smart phone application and then routing the relevant EV owner to the reserved charging station using a background navigation application if the proposed charging

Authorized licensed use limited to: b-on: UNIVERSIDADE DO PORTO. Downloaded on February 18,2021 at 19:14:25 UTC from IEEE Xplore. Restrictions apply.

station is approved. This condition is proposed to consider as a possible topic of future research in this manner.

ACKNOWLEDGMENT

This work was supported by Energy Market Regulatory Authority of Turkey (EPDK) R&D Funds (project “The Investigation of the Effects of Electric Vehicles and Charging Stations on Power Grid and Development of Required National Software to Optimize These Loads”) and The Scientific and Technological Research Council of Turkey (TUBITAK) under project Grant No.119E215. J.P.S. Catalão also acknowledges the support by FEDER funds through COMPETE 2020 and by Portuguese funds through FCT, under POCI-01-0145-FEDER-029803 (02/SAICT/2017).

REFERENCES

[1] Outlook, IEA Global EV. "to Electric Mobility." IEA: Paris, France (2019).

[2] R. Li, Q. Wu, S. S. Oren, “Distribution Locational Marginal Pricing for Optimal Electric Vehicle Charging Management”, *IEEE Trans. Power Systems*, vol. 29, pp. 203-211, 2014.

[3] X. Xi, R. Sioshansi, “Using Price-Based Signals to Control Plug-in Electric Vehicle Fleet Charging”, *IEEE Trans. Smart Grid*, vol. 5, pp. 1451-1464, 2014.

[4] Z. Liu, Q. Wu, S. S. Oren, S. Huang, R. Li, L. Cheng, “Distribution Locational Marginal Pricing for Optimal Electric Vehicle Charging Through Chance Constrained Mixed-Integer Programming”, *IEEE Trans. Smart Grid*, vol. 9, pp. 644-654, 2018.

[5] M. B. Rasheed, M. Awais, T. Alquthami, I. Khan, “An Optimal Scheduling and Distributed Pricing Mechanism for Multi-Region Electric Vehicle Charging in Smart Grid”, *IEEE Access*, vol. 8, pp. 40298-40312, 2020.

[6] R. Xie, W. Wei, Q. Wu, T. Ding, S. Mei, “Optimal Service Pricing and Charging Scheduling of an Electric Vehicle Sharing System”, *IEEE Trans. Vehicular Technology*, vol. 69, pp. 78-89, 2020.

[7] Y. Nie, X. Wang, K. W. E. Cheng, “Multi-Area Self-Adaptive Pricing Control in Smart City with EV User Participation”, *IEEE Trans. Intelligent Transportation Systems*, vol. 19, pp. 2156-2164, 2018.

[8] N. Y. Soltani, S. J. Kim, G. B. Giannakis, “Real-Time Load Elasticity Tracking and Pricing for Electric Vehicle Charging”, *IEEE Trans. Smart Grid*, vol. 6, pp. 1303-1313, 2015.

[9] Y. Zhang, P. You, L. Cai, “Optimal Charging Scheduling by Pricing for EV Charging Station with Dual Charging Modes”, *IEEE Trans. Intelligent Transportation Systems*, vol. 20, pp. 3386-3396, 2019.

[10] W. Yuan, J. Huang, Y. J. Zhang, “Competitive Charging Station Pricing for Plug-In Electric Vehicles”, *IEEE Trans. Smart Grid*, vol. 8, pp. 627-639, 2017.

[11] A. Laha, B. Yin, Y. Cheng, L. X. Cai, Y. Wang, “Game Theory Based Charging Solution for Networked Electric Vehicles: A Location-Aware Approach”, *IEEE Trans. Vehicular Technology*, vol. 68, pp. 6352-6364, 2019.

[12] W. Lee, R. Schober, V. W. S. Wong, “An Analysis of Price Competition in Heterogeneous Electric Vehicle Charging Stations”, *IEEE Trans. Smart Grid*, vol. 10, pp. 3990-4002, 2019.

[13] M. Alizadeh, H. T. Wai, M. Chowdhury, A. Goldsmith, A. Scaglione, T. Javidi, “Optimal Pricing to Manage Electric Vehicles in Coupled Power and Transportation Networks”, *IEEE Trans. Control of Network Systems*, vol. 4, pp. 863-875, 2017.

[14] X. Li, Y. Xiang, L. Lyu, C. Ji, Q. Zhang, F. Teng, Y. Liu, “Price Incentive based Charging Navigation Strategy for Electric Vehicles”, *IEEE Trans. Industry Applications*, article in press, 2020.

[15] S. Zhou, Y. Qiu, F. Zou, D. He, P. Yu, J. Du, X, Luo, C. Wang, Z. Wu, W. Gu, “Dynamic EV Charging Pricing Methodology for Facilitating Renewable Energy with Consideration of Highway Traffic Flow”, *IEEE Access*, vol. 8, pp. 13161-13178, 2020.

[16] A. Moradipari, M. Alizadeh, “Pricing and Routing Mechanisms for Differentiated Services in an Electric Vehicle Public Charging Station Network”, *IEEE Trans. Smart Grid*, vol. 11, pp. 1489-1499, 2020.

[17] A. S. A. Awad, M. F. S. Awad, T. H. M. El-Fouly, E. F. El-Saadany, M. M. A. Salama, “Optimal Resource Allocation and Charging Prices for Benefit Maximization in Smart PEV-Parking Lots”, *IEEE Trans. Sustainable Energy*, vol. 8, pp. 906-915, 2017.

[18] J. Yang, Y. Xu, Z. Yang, “Regulating the Collective Charging Load of Electric Taxi Fleet via Real-Time Pricing”, *IEEE Trans. Power Systems*, vol. 32, pp. 3694-3703, 2017.

[19] C. Fang, H. Lu, S. Liu, J. Chang, “Dynamic Pricing for Electric Vehicle Extreme Fast Charging”, *IEEE Trans. Intelligent Transportation Systems*, article in press, 2020.

[20] S. Aznavi, P. Fajri, M. Shadmand, A. K. Sadigh, “Peer-to-Peer Operation Strategy of PV Equipped Office Buildings and Charging Stations Considering Electric Vehicle Energy Pricing”, *IEEE Trans. Industry Applications*, article in press, 2020.

[21] S. Wang, S. Bi, Y. J. A. Zhang, “Reinforcement Learning for Real-Time Pricing and Scheduling Control in EV Charging Stations”, *IEEE Trans. Industrial Informatics*, article in press, 2020.

[22] Z. Moghaddam, I. Ahmad, D. Habibi, M. A. S. Masoum, “A Coordinated Dynamic Pricing Model for Electric Vehicle Charging Solutions”, *IEEE Trans. Transportation Electrification*, vol. 5, pp. 226-238, 2019.

[23] N. R. Asr, M. Y. Chow, J. Chen, R. Deng, “Distributed Real-Time Pricing Control for Large-Scale Unidirectional V2G with Multiple Energy Suppliers”, *IEEE Trans. Industrial Informatics*, vol. 12, pp. 1953-1962, 2016.

[24] D. Qiu, Y. Ye, D. Papadaskalopoulos, G. Strbac, “A Deep Reinforcement Learning Method for Pricing Electric Vehicles with Discrete Charging Levels”, *IEEE Trans. Industry Applications*, article in press, 2020.

[25] Q. Zhang, Z. Ding, W. Tan, W. Xie, Y. Li, “Negotiation Strategy of Discharging Price Between Power Grid and Electric Vehicles Considering Multi-Agent”, *IET Generation, Transmission&Distribution*, vol 14, pp. 833-844, 2020.

[26] H. Liu, Y. Zhang, S. Zheng, Y. Li, “Electric Vehicle Power Trading Mechanism Based on Blockchain and Smart Contract in V2G Network”, IEEE Access, vol. 7, pp. 160546-160558, 2019.

[27] M. Carrion, “Determination of the Selling Price Offered by Electricity Suppliers to Electric Vehicle Users”, *IEEE Trans. Smart Grid*, vol. 10, pp. 6655-6666, 2019.

[28] A. Ghosh, V. Aggarwal, “Menu-Based Pricing for Charging of Electric Vehicles with Vehicle-to-Grid Service”, *IEEE Trans. Vehicular Technology*, vol. 67, pp. 10268-10280, 2018.

[29] E. S. Rigas, S. D. Ramchurn, N. Bassiliades, “Managing Electric Vehicles in the Smart Grid Using Artificial Intelligence: A Survey”, *IEEE Trans. Intelligent Transportation Systems*, vol. 16, pp. 1619-1635, 2015.

[30] I. Sengor, O. Erdinc, B. Yener, A. Tascikaraoglu, J. P. S. Catalao, “Optimal Energy Management of EV Parking Lots Under Peak Load Reduction Based DR Programs Considering Uncertainty”, *IEEE Trans. Sustainable Energy*, vol. 10, pp. 1034-1043, 2019.

[31] H. C. Guldorum, A. K. Erenoglu, I. Sengor, O. Erdinc, J. P. S. Catalao, “An Interoperability Platform for Electric Vehicle Charging Service Considering Dual System Operator and Electric Vehicle Owner Sides”, *2nd International Conference on Smart Energy Systems and Technologies (SEST)*, Porto, Portugal, September 9-11, 2019.

Authorized licensed use limited to: b-on: UNIVERSIDADE DO PORTO. Downloaded on February 18,2021 at 19:14:25 UTC from IEEE Xplore. Restrictions apply.