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Profit Maximization for EVSEs-Based Renewable Energy Sources in Smart Cities With Different Arrival Rate Scenarios

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ABSTRACT This paper proposes a profit maximization model for a Decentralized Electric Vehicle Supply Equipment (D-EVSE) equipped with a renewable energy sources system such as a solar energy system. We acknowledge a power connection to the central power grid when necessary. We allow EV to offer its surplus power as discharging power processes. We design a Decentralized Profit Maximization Algorithm (DPMA) to help D-EVSEs take profit from the electricity price variation during the day when selling or buying electricity respectively to EVs or from the grid or EVs as discharging processes. Finally, numerical simulations with MATLAB are conducted to prove the effectiveness of our proposed solution.

INDEX TERMS Electric vehicles, electric vehicles supply equipment, decentralized-energy storage system, decentralized-electric vehicle supply equipment, profit maximization, photovoltaic system, smart cities, solar energy.

I. INTRODUCTION

Curbing of air pollutions and Greenhouse Gas Emissions (GHGs) from transportation and non-renewable power plants in the smart city [1] is vital in providing a clean and green environment. As an action from many governments aiming to minimize the effect of transportation's pollution upon the climate, new plans have been were announced to ban cars with gas engines throughout the world. For example, the UK, Sweden, France, Germany, and Australia plan to ban such vehicles by 2035 [2]–[4]. As these plans unfold, the presence of EVs will grow very fast globally, especially in countries such as Canada, where citizens are encouraged by several types of financial incentives to buy EVs [5]. Consequently, the necessity of initiating Electric Vehicles Supply Equipment (EVSE) in the smart city in the form of public charging stations is growing incrementally year by year. The EVSE will offer and fulfill the EVs' charging demand.

However, only allowing EVs charging process via EVSEs, which are primarily connected to the power grid, will put pressure upon the centralized power grid, especially during peak demand periods. For a centralized power grid, increasing the power production using non-renewable energy sources (nuclear and gas) will increase the environmental impacts by increasing the GHGs. Moreover, the massive power demands will affect the power grid's reliability and lead to increased costs of grid maintenance and degradation [6]. Thus, we promote the option to switch from EVSE based on non-renewable energy to decentralize the EVSE (D-EVSE) based on Renewable Energy Sources (RESs) and an Energy Storage System (ESS).

D-EVSE is a promising solution and brings more benefits than the EVSE which obtains power only from the power grid. These benefits include increasing the quality of charging power and offering the flexibility of EV charging power based on its ability as well as eliminating power line losses. Moreover, unused generated power will be stored. Overall, the D-EVSE will facilitate the integration of a massive number of EVs in smart cities without causing an additional power load that may jeopardize the power grid's resilience and reliability [6]–[8].

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In this paper, we propose an optimization model aiming to maximize the D-EVSEs' profits. Each D-EVSE will manage its charging processes and maximize its profits by using the proposed model. Our proposed model also takes into account the D-EVSEs' sustainability while maximizing the D-EVSEs' profits. In the proposed model, we consider that the D-EVSE is primarily powered by solar energy and equipped with ESS to store the generated power. The D-EVSE is not an entirely decentralized EVSE because it has a connection to the power grid. The D-EVSE manages the power grid's interconnection and uses it to request power from the power grid. However, the power requisition will be used only when the D-EVSE does not have enough stored power in the ESS.

In summary, our major contributions of the paper are presented as follows:

- First, we design a maximization profit model to manage and control EVs' charging and discharging processes.
- Second, we propose a Decentralized Profit Maximization Algorithm (DPMA) based on RESs, power grid, and EV discharging prices to help D-EVSEs take profit from the electricity price variation during the day.
- Third, we consider five EV arrival rates to examine our proposal. Also, we illustrate Time of Use (ToU) pricing in our model.
- Fourth, we present the results of the numerical simulation followed by a discussion to prove our proposed solution's effectiveness.
- Finally, we take into account the preservation of the D-EVSEs' sustainability in our proposed algorithm.

The rest of this paper is organized as follows. Section II reviews the related works. Section III defines the proposed system model and problem formulation. In Section IV, performance evaluations are addressed. Finally, Section V concludes this paper.

II. RELATED WORKS

The challenges of EV charging and discharging processes at EVSE in the smart city have attracted the interest of many researchers from academic and industrial perspectives. The EVSE infrastructure deployment was investigated in [9]–[12]. A comprehensive survey of the EVs' challenges to the power grid is presented in [13]. The EV charging price is an important aspect for EV drivers and EVSE owners. EV charging price strategies are studied in [14]–[20]. Other areas have been studied, such as minimizing the waiting time for EV charging [21], [22], discharging processes [23]–[25], and reducing EV's charging cost [26]. Another perspective is that the EVSE owners must also benefit [26], [27]. The benefitting of EVSE owners, such as by increasing their profits, will allow EVSE to be diffused in the city. Several studies using many different techniques in [28]–[30] have investigated how to increase the profit for the power provider and the EV owner. In general, we have divided the related works of the EVSE charging and discharging benefit management studies into three groups based on the EVSE power source: 1) EVSE based on the power grid, 2) EVSE based on the power grid and PV, and 3) EVSE based on the power grid, the wind turbine, and the PV.

Many studies have investigated EV charging impact and discharging benefit management in EVSE powered from the power grid [31]–[34]. The authors of [35] presented A plug-in hybrid electric vehicle (PHEV) power management system based on GT aiming to reduce the PHEV charging and battery degradation costs for each PHEV owner. The presented system considered the source of power to be the power grid. The system investigated the PHEV patterns when gas and energy prices were changed; as well, trip distance and trip time were considered. A stochastic model was introduced in [36]. This model implemented the two cases of dynamic pricing and optimal scheduling to examine the presented model. The model studied the price influence on the revenue of the PHEV charging station. The authors concluded that the presented model showed a positive outcome. However, these papers did not study the influence of EV power demands on the power grid.

The EV charging and discharging processes benefitting management in EVSE powered from the power grid and PV are introduced in [37], [38]. An optimization and controlling scheme are presented in [26]. The presented scheme proposed an EVSE for charging and discharging processes. The target of the proposed scheme is to minimize the final operational cost. The EVSE is connected to the power grid and equipped with a PV power production and ESS. In addition, a large building was linked to the EV bidirectional station to purchase energy whenever needed. The power price technique is based on real-time pricing for charging as well as discharging services. However, the EVSE is powered by the power grid and stores the ESS's power when the power grid's price is low. An optimization charging model is presented in [37] for EVSE located in a parking lot. The EVSE is based on the power grid, and the PV is linked to ESS as well as to the power grid. The given model, which aimed to reduce the charging cost, used ToU pricing. The study concluded that the presented model reduced the charging cost and enhanced the EV arrival rate.

The authors of [39] designed EVSE as a charging station for charging and discharging processes; in this case, the EVSE was equipped with RESs. The charging station offered a price for each EV wanting to sell its surplus power. In this study, the EVs' owners were able to accept or decline the offer. The sold power from EVs was injected into the power grid. Likewise, the authors of [39] presented an online pricing approach for EV charging or discharging requests in [40]. This paper used the same mechanism as that which was used in [39]. Both papers allowed the EV owner to choose the extended deadline to reduce the charging cost and aimed to maximize the charging station and EV owners' revenue with a fixed profit pricing strategy. However, the authors of paper [40] did not consider the discharging process in their study. All of these studies used the power grid as the primary

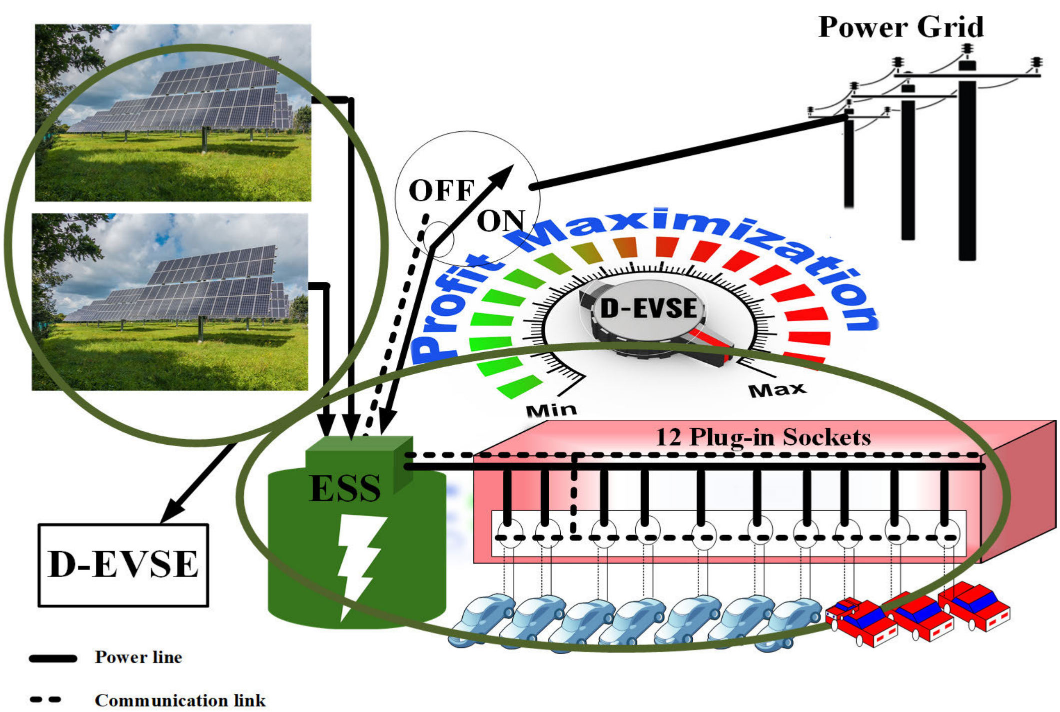

FIGURE 1. Overview of our proposed model.

power source to the EVSE, and there were no investigations into the EVSE's impacts on the power grid.

Other researchers have examined the benefit of managing EV charging and discharging processes in EVSE powered from the power grid, the wind turbine, and the PV [41], [42]. Two case studies presented in [43] aimed to minimize the power generation cost (wind and grid) and investigate the EV traffic congestion. The wind turbines were connected with the power grid. The EV profits were considered in the study. In this study, all EVs were allowed to schedule charging or discharging services to control the traffic. The conclusion was that the presented model minimized the power generation cost and the delivery cost while avoiding traffic congestion.

The authors of [44] presented a risk-based auction with an adaptive bidding energy trading system. The presented system aimed to maximize the bidding energy trading revenue by using the competitive equilibrium price prediction. The authors of [45] proposed an iterative double auction model to facilitate energy trading between participants using a central controller. The proposed model used a distributed algorithm to maximize the individual utility profits and the profits of participants. These studies considered the power grid to be the primary power source and did not show the power demand's effect on the power grid. A game-theoretic approach based on the decentralized electric vehicle charging schedule was implemented in [6] to minimize the EV charging expenses and increase the power grid performance. The real-time price system was used to increase the power grid's profits and the EV owners' profits. Also, the battery degradation cost and characteristics were both taken into account. The EV charging location was at owner's home with the day-ahead request scheme. Paper [46] proposed a game theoretical-based framework model to facilitate energy trading decisions with the distributed ESSs. All ESSs could decide the maximum amount of trading energy in the utility. However, the proposed model has a trade-off between the profits and costs of energy trading.

Unlike these studies, in this paper, we consider RESs as the primary power source for the D-EVSEs (as a green energy sources) and include EV charging and discharging processes. We propose a Decentralized Profit Maximization Algorithm (DPMA) to optimize the D-EVSEs' profits and maintaining the stations' sustainability. However, in case of bad weather, a connection to the power grid is used to fulfill the EVs' demands.

III. SYSTEM MODEL AND PROBLEM FORMULATION

In this section, we consider D-EVSE as a public charging station based on RESs (Solar Energy) and equipped with ESSs, as shown in Figure. 1.We assume that each D-EVSE has 12 plug-in sockets, and each plug-in socket has 108 time slots [6 (time slots in each hour) *18 (hours) = 108 time slots]. We assume that the D-EVSE uses a fast charging process with 180 kWh as charging rate [47]. The ESS consists of many connected batteries, and each battery has its cable connected to the station. These batteries are considered one big battery managed by D-EVSE. During the daytime, the ESS will be charged from solar energy production. During the nighttime, the D-EVSE will be charged from the power grid if there is not enough power in the ESS.

We suppose that each D-EVSE calculates the total power cost and sets its profit. The D-EVSE broadcasts the charging price to all EVs on the road. The EV charging price is based primarily on the power source, and the discharging service price is based on the needs of the D-EVSE. The D-EVSE operation time extends from 6 a.m. until 12 a.m.

At the beginning of the day, the D-EVSE gathers the power source information from ESS, and then the price is determined. The symbol X represents the D-EVSE's charging prices. Eq. 1 gives the D-EVSE's charging price X_j when the D-EVSE is powered only from the solar energy source:

$$X_j(t) = P_j^{pr}(t) \tag{1}$$

where:

- X_j: D-EVSE's charging price [cent/kWh]
- j: D-EVSE's number
- P_j^{pr}: RESs power price [cent/kWh]
- t: time variation

If the D-EVSE is powered from the power grid, then the X is given by Eq. 2:

$$X_j(t) = C_j^{G^{pr}}(t) \tag{2}$$

where:

- $C_j^{G^{pr}}$: cost of power from the power grid [cent/kWh]

In the case of purchasing power from EVs as discharging power, the X_j is given by Eq. 3:

$$X_j(t) = C_j^{EV_i}(t) \tag{3}$$

where:

- $C_j^{EV_i}(t)$: EV discharging power price
- EV_i: EV number

$$C_j^{EV_i}(t) = Pr_{dis}^{EV_i}(t) + [Pr_{dis}^{EV_i}(t) * 25\%] \tag{4}$$

where:

- $Pr_{dis}^{EV_i}(t)$: EV discharging power cost

In our model, we assume that all EVs can reach all D-EVSEs and communicate wirelessly with each other. Each EV on the road calculates its ability to reach the final destination by using Eq. 5 and Eq. 6:

$$SoC_{Trip}^{EV_i} = Trip^i \times D_{rate} \tag{5}$$

where:

- SoC: state of charge
- $SoC_{Trip}^{EV_i}$: required SoC to reach final destination
- $Trip^i$: distance between EV and final destination
- D_{rat}: EV consumption rate

$$dSoC^{EV_i}(t) = SoC_{Int}^{EV_i} - [SoC_{Trip}^{EV_i} + SoC_{\min}^{EV}] \tag{6}$$

where:

- $SoC_{Int}^{EV_i}$: initial EV SoC
- $SoC_{\min}^{EV}$: minimum EV SoC

EV computes the charging time and the charging power by using Eqs. 7 and 8 respectively [48]:

$$t_{ch}^{EV_i}(t) = \frac{SoC_{ch}^{EV_i}(t)}{R_{ch}} \tag{7}$$

$$SoC_{ch}^{EV_i}(t) = |dSoC^{EV_i}(t)| \tag{8}$$

where:

- $t_{ch}^{EV_i}(t)$: EV charging time
- R_{ch}: charging rate

The EV discharging time and the discharging power from EV are given by Eqs. 9 and 10 respectively [23], [49]:

$$t_{dis}^{EV_i}(t) = \frac{SoC_{dis}^{EV_i}(t)}{R_{dis}} \tag{9}$$

$$SoC_{dis}^{EV_i}(t) = dSoC^{EV_i}(t) \tag{10}$$

where:

- $t_{dis}^{EV_i}(t)$: EV discharging time
- R_{dis}: discharging rate

If each D-EVSE has an available plug-in socket for discharging process, then the D-EVSE will admit EV to discharge its surplus power. Eq.11 calculates the cumulative total amount of sold power from EVs.

$$SoC_{EV}^{\mathrm{ESS}_j}(t) = \sum SoC_{dis}^{EV_i}(t) \tag{11}$$

where:

- $SoC_{EV}^{\mathrm{ESS}_j}(t)$: cumulative total amount of sold power from EVs

Eq. 12 used to calculate the amount of power that will be requested from the power grid.

$$SoC_{G_{req}}^{\mathrm{ESS}_j}(t) = SoC_{ch}^{EV_i}(t) + SoC_{min}^{ESS} - SoC_{RES}^{ESS_j}(t) - SoC_{dis}^{EV_i}(t) \tag{12}$$

where:

- $SoC_{G_{req}}^{\mathrm{ESS}_j}$: amount of power purchased from the power grid
- $SoC_{\min}^{ESS}$: minimum power in ESS
- $SoC_{RES}^{\mathrm{ESS}_j}$: amount of power from solar energy

The total amount of the power purchased from the power grid is given by Eq. 13:

$$SoC_G^{\mathrm{ESS}_j}(t) = \sum SoC_{G_{req}}^{\mathrm{ESS}_j}(t) \tag{13}$$

where:

- $SoC_G^{\mathrm{ESS}_j}$: amount of power purchased from power grid

The total amount of the power in the ESS_j is given by Eq. 14:

$$SoC^{\mathrm{ESS}_j}(t) = SoC_{RES}^{\mathrm{ESS}_j}(t) + SoC_G^{\mathrm{ESS}_j}(t) + SoC_{EV}^{\mathrm{ESS}_j}(t) \tag{14}$$

where:

- SoC^{ESS_j}: ESS current battery level

All power generated from RESs is added into ($SoC_{RES}^{ESS_j}(t)$). At the beginning of the D-EVSE's operations, the P_j^{pr}(t) is based on the total amount of power that comes from RES ($SoC_{RES}^{\text{ESS}_j}(t)$). However, the $SoC_{RES}^{\text{ESS}_j}(t)$ must not reach 20% of its battery capacity. If the D-EVSE requests power from the power grid, then the purchasing power from the power grid is added into $SoC_G^{ESS_j}(t)$. In addition, all power purchased from the EVs as discharging processes is added into $SoC_{EV}^{ESS_j}(t)$.

Each D-EVSE which has sold power will update its sold power tracker $SoC_{sold}^{\text{D-EVSE}_j}(t)$ immediately to maintain sustainability as shown in Eq.15

$$SoC_{sold}^{\text{D-EVSE}_j}(t) = \sum SoC_{ch}^{EV_i}(t) \tag{15}$$

where:

- $SoC_{sold}^{\text{D-EVSE}_j}(t)$: cumulative total amount of sold power to EV

The D-EVSE battery status is calculated by using Eq. 16.

$$SoC^{\text{D-EVSE}_j}(t) = SoC^{\text{ESS}_j}(t) - SoC_{sold}^{\text{D-EVSE}_j}(t) \tag{16}$$

- $SoC^{\text{D-EVSE}_j}(t)$: D-EVSE battery status

Each D-EVSE will receive the request messages from EVs, and the D-EVSE will use the proposed model to maximize its profits. The D-EVSE's profits will be calculated based on the source of the sold power to EVs. Therefore, the D-EVSE uses Eq. 17 to calculate its profits when the power source is from the RES:

$$F_j(t) = SoC_{ch}^{EV_i}(t) \times [X_j - P_j^{co}(t)] \tag{17}$$

where:

- F_j(t): D-EVSE's profit
- P_j^{co}: RESs power cost [cent/kWh]

If the source of power is from the power grid, then the D-EVSE calculates its profit by using Eq. 18:

$$F_j(t) = SoC_{ch}^{EV_i}(t) \times [X_j - C_j^{G^{co}}(t) + I_j^G(t)] \tag{18}$$

- $C_j^{G^{co}}(t)$: power grid power cost [cent/kWh].
- $I_j^G(t)$: Incentive from grid to the D-EVSE [cent/kWh].

The D-EVSE's profit in the case of drawing power from EVs as discharging power is given by Eq. 19:

$$F(t) = SoC_{ch}^{EV_i}(t) \times [X_j - C_j^{EV}(t)] \tag{19}$$

- $C_j^{EV}(t)$: EV discharging power cost [cent/kWh].

Eq. 21 is our objective function, and it is used to maximize the D-EVSEs profit. Furthermore, our objective function has objective function constraints.

$$Maximize\ F_j(t) \tag{20}$$

Subject to :

$$SoC_{min}^{ESS} \leq SoC_{RES}^{ESS_j}(t) + SoC_G^{\text{ESS}_j}(t) + SoC_{EV}^{\text{ESS}_j}(t) \tag{21}$$

Algorithm 1 Decentralized Profit Maximization Algorithm (DPMA)

Input D-EVSE [J, $SoC_{ch}^{EV_i}$ (t), $SoC_{dis}^{EV_i}$ (t), $SoC_{\min}^{\text{ESS}}$, $SoC^{\text{D-EVSE}_j}(t)$]

for j = 1 .. J **do**
  if $SoC^{D\text{-}EVSE_j}(t) > SoC_{\min}^{ESS}$ **then**
    Obtain the power price ($P_j^{pr}(t)$) and cost (P_j^{co}) from Tables 3&5
    Maximize the profit according to Eqs.17&21
    update $SoC_{sold}^{\text{D-EVSE}_j}(t)$ according to Eq. 15
    update $SoC^{\text{D-EVSE}_j}(t)$ according to Eq.16
  else
    if *there are EVs scheduled for discharging process* **then**
      Obtain the power price ($Pr_{dis}^{EV_i}(t)$) and cost ($C_j^{EV}(t)$) from Tables 3&5
      Maximize the profit according to Eqs.19&21
      update $SoC_{sold}^{\text{D-EVSE}_j}(t)$ according to Eq. 15
      update $SoC_{EV}^{\text{ESS}_j}(t)$ according to Eq.11
      update $SoC^{\text{D-EVSE}_j}(t)$ according to Eq.16
    end if
    if *the amount of power from EV discharging process is not enough* **then**
      Obtain the amount of power from the power grid according to Eq.12
      Based on the time of request:
      Obtain the power price ($C_j^{G^{pr}}$ & power cost ($C_j^{G^{co}}$)from Tables 2 & 4
      Obtain the incentive price ($I_j^G(t) =$) from Table 1
      Maximize the profit according to Eq.s18&21
      update $SoC_{sold}^{\text{D-EVSE}_j}(t)$ according to Eq. 15
      update $SoC_G^{\text{ESS}_j}(t)$ according to Eq.13
      update $SoC_{EV}^{\text{ESS}_j}(t)$ according to Eq.11
      update $SoC^{\text{D-EVSE}_j}(t)$ according to Eq.16
    end if
  end if
end for

$$SoC_{max}^{ESS} \geq SoC_{RES}^{ESS_j}(t) + SoC_G^{\text{ESS}_j}(t) + SoC_{EV}^{\text{ESS}_j}(t) \tag{22}$$

$$SoC_{ch}^{EV_i}(t) \geq 10 \tag{23}$$

$$SoC_{dis}^{EV_i}(t) \geq 10 \tag{24}$$

where:

- $SoC_{\max}^{ESS}$: maximum power in ESS

We use Algorithm 1 to test our decentralized profit maximization algorithm (DPMA). The proposed model is initiated once the D-EVSE receives the requested messages from the EVs.

TABLE 1. Simulation parameters.

$SoC_{RES}^{\mathrm{ESS}_j}$	Random 11.5 - 19 MW
$SoC_{\max}^{\mathrm{ESS}}$ kW	100
$SoC_{\min}^{\mathrm{ESS}}$ kW	20
ESS max capacity [50]	30 MW
Number of D-EVSEs J	12
Operation time	6 a.m. - 12 a.m.
Number of plug-in sockets	12 [47]
Number of time slots (t)	108/h
Charging rate R_{ch} [51]	30 kW/t
Discharging rate R_{dis} [51]	30 kW/t
Duration of time slot	10 min
Time of incentive price and grid pricing	off-peak (6 a.m. - 7 a.m. and 7 p.m. - 12 a.m.) mid-peak (7 a.m. - 11 a.m. and 5 p.m. - 7 p.m.) on-peak (11 a.m. - 5 p.m.)
Incentive price from grid $I_j^G(t)$	off-peak (0.05 CAN$/kWh) mid-peak (0.03 CAN$/kWh) on-peak (0.015 CAN$/kWh)
Number of EVs I	12000
$SoC_{ch}^{EV_i}$	Random 0 - 80 kW
$SoC_{dis}^{EV_i}$	Random 0 - 50 kW

TABLE 2. List of power grid power costs based on ToU pricing.

Power grid cost $C_j^{G^{co}}$ on-peak	0.217 CAN$/ kW
Power grid cost $C_j^{G^{co}}$ mid-peak	0.15 CAN$/ kW
Power grid cost $C_j^{G^{co}}$ off-peak	0.105 CAN$/ kW

TABLE 3. List of RESs and EV discharging costs.

Renewable energy cost P_j^{co}	0.10 CAN$/ kW
EV discharging power cost $Pr_{dis}^{EV_i}(t)$ on-peak	0.12 CAN$/ kW

TABLE 4. List of D-EVSE selling price based on ToU pricing.

Power grid price $C_j^{G^{pr}}$ on-peak	0.24.95 CAN$/ kW
Power grid price $C_j^{G^{pr}}$ mid-peak	0.17.25 CAN$/ kW
Power grid price $C_j^{G^{pr}}$ off-peak	0.12.025 CAN$/ kW

TABLE 5. List of RESs' and EV's discharging prices.

RES charging price $P_j^{pr}(t)$	0.18 CAN$/ kW
EV discharging power price $C_j^{EV}(t)$ on-peak	0.15 CAN$/ kW

IV. PERFORMANCE EVALUATION

This section discusses the proposed model's performance described by the Decentralized Profit Maximization Algorithm (DPMA). We used MATLAB 2018b to perform our simulation. We consider 12 D-EVSEs with each D-EVSE having RESs prediction (solar panel). The RESs prediction is connected with ESS. The ESS storage capacity is 30 MW. We suppose that all D-EVSEs are equipped with a DC fast charger, and each D-EVSE has 12 plug-in sockets for EV charging and EV discharging.

Each D-EVSE will broadcast its charging price X_j and charging availability schedule every five minutes. All D-EVDEs will operate from 6 a.m. until 12 a.m. We suppose that each D-EVSE will process the EVs for the charging process using the DPMA to either admit or reject the EV. Moreover, the D-EVSE will be based on a first-come, first-served basis and will send EVs a reservation confirmation. We assume that there are 12000 EVs distributed randomly on the roads. The simulation parameters are shown in Table 1.

The time of the incentive's prices and the incentive's prices from the power grid is shown on the simulation parameters' 2. The power price from the power grid will be based on the Time of Use (ToU) pricing in the city of Ottawa [52] (shown in Table 2).

The RESs and the EV discharging cost are shown in Table. 3.

In the case of bad weather such as a rainy or cloudy day, or in the case when the ESS_j does not have enough power in its battery, the D-EVSE will rely on the power grid and the price will be based on the ToU pricing. Table 4 shows the D-EVSE charging price based on the ToU pricing.

The RESs' and EV's discharging selling prices are shown in Table 5.

We assume that the proposed model is implemented in the city of Ottawa, Canada, in the summertime. The D-EVSEs' locations in the city of Ottawa are known and fixed. In this study, we consider the following:

- EV charging and discharging processes
- Ottawa's ToU pricing policy in the case of charging from the power grid as shown in Table 2
- additional 15% charging fees D-EVSE_j^{fees} in the case of charging from the power grid as shown in Table 4.

However, we do not consider the flowing parameters in our study:

- Battery Deep of Discharge (DoD)
- Time to live (TTL)

In our discussion, we calculate the D-EVSE price diversity and profit for each hour, and we show the average of the D-EVSE price diversity and the D-EVSE profit. We study the following five EV arrival scenario rates in our simulation discussion: our EV arrival rate estimation, Poisson distribution, homogeneous Poisson processes, and two scenarios with non-homogeneous Poisson processes intensity. To keep consistency in our explanation, we chose D-EVSEs 1 to 3 to present the performance of our proposed model. Moreover, D-EVSEs-AVG shows average performance of our proposed model in all D-EVSEs. There is no rational reason behind choosing D-EVSEs 1 to 3 because, in some

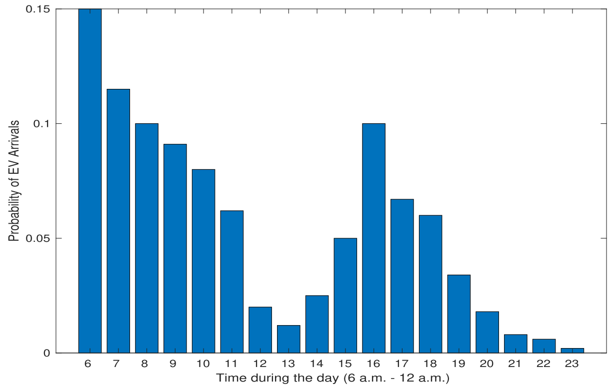

FIGURE 2. EV arrival rates with our arrival rate estimation.

cases, the D-EVSEs-AVG perform much better than the presented D-EVSEs 1 to 3, which means the other D-EVSEs obtained better performance than the illustrated stations. Each D-EVSE will have a random amount of power from Renewable Energy Sources (RESs) $SoC_{RES}^{ESS_j}$ between 11.5 to 19 MW. Also, each D-EVSE will receive a random number of EVs with their unanticipated power demand $SoC_{ch}^{EV_i}(t)$.

A. EV ARRIVAL RATES WITH OUR ARRIVAL RATE ESTIMATION

In this scenario, the EV arrival rates in D-EVSEs are based on the probability shown in Figure. 2. The EV arrival rates are based on our estimation [53].

Figure. 3 compares the price diversities between D-EVSEs 1 to 3 and the average of all 12 D-EVSEs (D-EVSEs-AVG). The price at the beginning of the operation time is almost the same in D-EVSE-1 and D-EVSEs-AVG; however, the D-EVSE-3 is almost completely reliant on the RES's price while D-EVSE-2 is almost dependent on the power grid's price. During the RESs' power production time from (10 a.m. - 4 p.m.), the amount of generated energy from RESs contributes enough power for the stations. It mitigates the power load on the power grid. However, at the time (12 p.m. - 3 p.m.), the D-EVSEs are almost completely reliant on RESs power production and price.

Table 6 shows the average charging price based on the RESs, the power grid, and the EV discharging power prices. As shown in Table 6, the average charging price during the mid-peak time (7 a.m. - 11 a.m.) is between 17.66 to 17.86 cents in CAN\$/kW. The RESs power price is 18 cents in CAN\$/kW, and the power grid price during mid-peak is 17.25 cents in CAN\$/kW as shown in Tables 5 and 4. This means that all D-EVSEs depend more on the RESs power than on the power grid as depicted in Table 6. However, during the on-peak time (11 a.m. - 5 p.m.), the average charging prices rely on RESs' price. From (5 p.m. -7 a.m.) the charging price is between 16.88 to 17.17 cents in CAN\$/kW. This means that the EV discharging processes also affect the charging prices because the power grid price is 17.25 cents in CAN\$/kW at mid-peak while the EV discharged power price is 15 cents in CAN\$/kW as presented

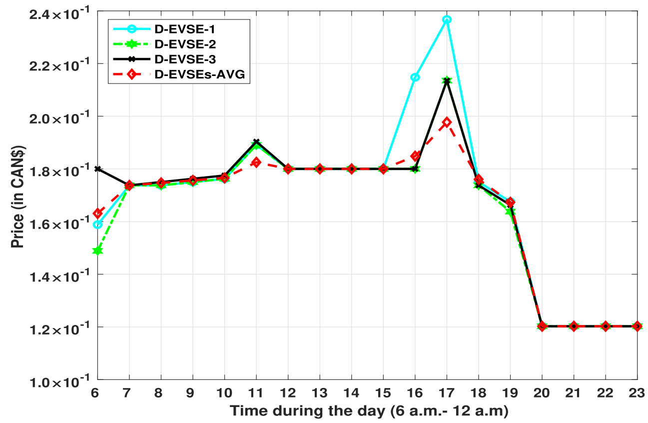

FIGURE 3. Average of the D-EVSEs' diverse charging price comparing D-EVSEs 1 - 3 with D-EVSEs-AVG of the 12 D-EVSEs.

TABLE 6. Average D-EVSEs' charging price (in CAN\$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	1.588×10^{-1}	1.489×10^{-1}	1.800×10^{-1}	1.631×10^{-1}
7 a.m. - 11 a.m.	1.776×10^{-1}	1.776×10^{-1}	1.786×10^{-1}	1.766×10^{-1}
11 a.m. - 5 p.m.	1.952×10^{-1}	1.856×10^{-1}	1.856×10^{-1}	1.838×10^{-1}
5 p.m. - 7 p.m.	1.713×10^{-1}	1.688×10^{-1}	1.700×10^{-1}	1.717×10^{-1}
7 p.m. - 12 a.m.	1.203×10^{-1}	1.203×10^{-1}	1.203×10^{-1}	1.203×10^{-1}

in Tables 4 and 5 respectively. After sunset, the average charging price for all D-EVSEs is dependent on the power grid's price.

Figure. 4 compares the average profits of the D-EVSEs 1- 3 with all 12 D-EVSEs' average profits presented as D-EVSEs-AVG. The same figure with Figure 2 illustrates that when the EV charging demands are high and the amount of RESs' energy production is high, the profit increases accordingly and more specifically from (8 a.m. - 12 p.m.) and (2 p.m. - 4 p.m.). Therefore, the D-EVSE will get the most profits can get. However, when EV charging demands are low and the amount of RESs energy production is high such as between (12 p.m. - 2 p.m.), then the D-EVSE makes a fair profit. The D-EVSE profit starts decreasing from (6 p.m. - 12 a.m.) due to few EVs. The D-EVSEs rely on the power grid price, which also shows that all D-EVSEs obtained the lowest profit during the day.

As the results illustrate in Table 7, the total profit is compared with the average profit for all 12 D-EVSEs (D-EVSEs-AVG) during the ToU pricing classification. The D-EVSEs is most profitable when the RESs power production contributes to the power grid during mid-peak (7 a.m. -11 a.m.) and on-peak (11 a.m. -5 p.m.) as shown in Table 7. Table 7 also shows that the D-EVSEs-AVG profit is greater than the profit of D-EVSE-3 at the time (6 a.m. - 11 a.m.), which means that the other D-EVSEs

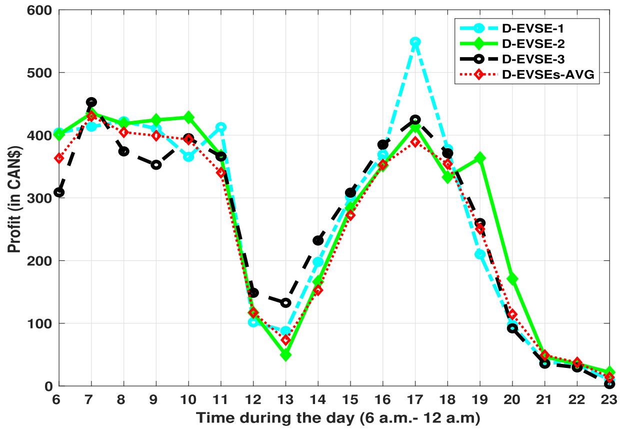

FIGURE 4. Average of the D-EVSEs' profits comparing D-EVSEs 1 - 3 with D-EVSEs-AVG of the 12 D-EVSEs.

TABLE 7. Average D-EVSEs' profit (in CAN$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	404.2	400.9	308.9	363.3
7 a.m. - 11 a.m.	2024.5	2073.1	1940.9	1967.6
11 a.m. - 5 p.m.	1606.8	1382.3	1631.5	1358.0
5 p.m. - 7 p.m.	587.9	696.6	631.1	604.5
7 p.m. - 12 a.m.	180.3	274.9	160.5	214.9

TABLE 8. Comparison of purchased power for D-EVSEs 1 - 3 and D-EVSEs-AVG.

	RESs	Power grid	EV Discharging power
D-EVSE- 1	57%	39%	4%
D-EVSE- 2	58%	40%	2%
D-EVSE- 3	72%	26%	2%
D-EVSE- AVG	68%	30%	2%

are more profitable than D-EVSE-2. However, during the on-peak period, D-EVSE-1 and D-EVSE-3 are far more profitable than D-EVSE-2 and D-EVSEs-AVG.

Table 8 shows the percentage of power contributed from RESs as well as the purchasing power from the power grid and EV discharging processes. The table shows that RESs' power contributes more than 57% of the total sold power. This means that the RESs are profitable for the D-EVSEs and have mitigated the power demand on the power grid. Also, the EV discharging processes have contributed 4% of the total sold power for D-EVSE-1 and 2% of the total sold power for the other D-EVSEs. Since this model's objective is to maximize profit, EV charging processes are prioritized.

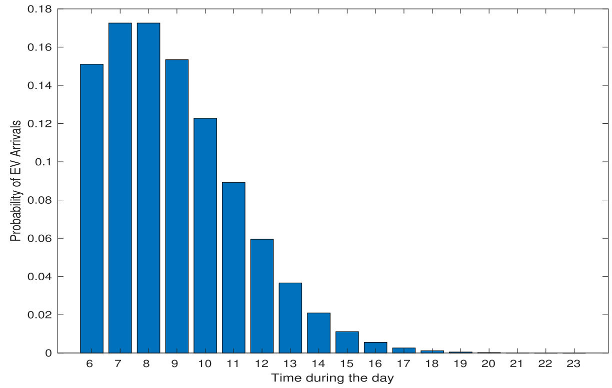

FIGURE 5. EV arrival rates with poisson distribution.

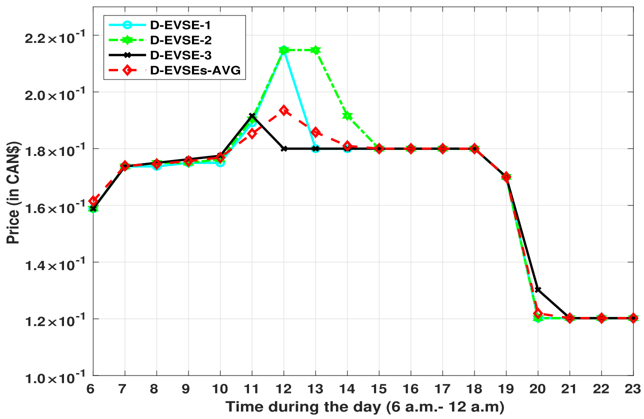

FIGURE 6. Average of the D-EVSEs' diverse charging prices comparing D-EVSEs 1 - 3 with D-EVSEs-AVG of the 12 D-EVSEs.

B. EV ARRIVAL RATES WITH POISSON DISTRIBUTION

Figure. 5 shows the probability of EV arrival rates. The EV arrival rate is assumed to be Poisson processes [54], [55] with an arrival rate $\lambda = 8$.

At the time between (7 a.m. - 10 a.m.) when there is a very high EV arrival rate with accompanying power demands, the average price for all D-EVSEs relies on the power grid price as shown in Figure 6. On the other hand, the same figure demonstrates that the D-EVSE-3 obtains enough power from the RESs from (12 p.m. - 6 p.m.). We can observe that all D-EVSEs are totally reliant on RESs between (3 p.m. - 6 p.m.) due to a low EV arrival rate.

Table. 9 illustrates the average charging price for all D-EVSEs. As we can see from this table, the average charging price at the time between (11 a.m. - 5 p.m.) is between 18 to 19.35 cents in CAN$/kW. This means that the power price is based on RESs' price because the power grid price at these times is 24.955 cents in CAN$/kW. In contrast, most D-EVSEs rely on the power grid price from (5 p.m. - 12 a.m.).

Due to a considerable number of EV arrivals between (7 a.m. - 11 a.m.), as shown in Figure 5, the D-EVSEs obtained the highest profit for all D-EVSEs. However, D-EVSE-2 and D-EVSE-1 obtained the highest profit

TABLE 9. Average charging price for D-EVSEs (in CAN$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	1.588×10^{-1}	1.588×10^{-1}	1.588×10^{-1}	1.615×10^{-1}
7 a.m. - 11 a.m.	1.773×10^{-1}	1.781×10^{-1}	1.788×10^{-1}	1.773×10^{-1}
11 a.m. - 5 p.m.	1.858×10^{-1}	1.935×10^{-1}	1.800×10^{-1}	1.834×10^{-1}
5 p.m. - 7 p.m.	1.750×10^{-1}	1.750×10^{-1}	1.750×10^{-1}	1.750×10^{-1}
7 p.m. - 12 a.m.	1.203×10^{-1}	1.203×10^{-1}	1.227×10^{-1}	1.207×10^{-1}

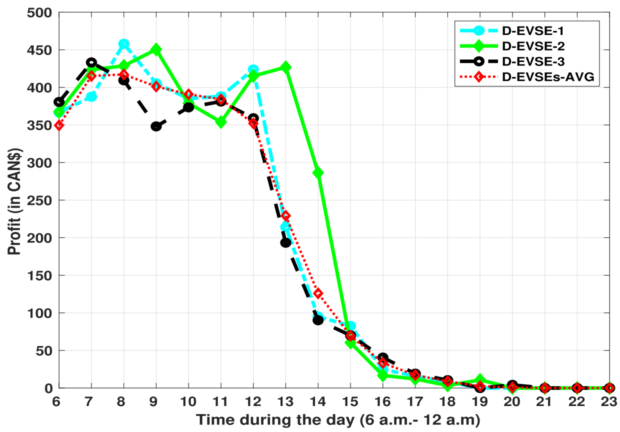

FIGURE 7. Average of the D-EVSEs' profits comparing D-EVSEs 1 - 3 with D-EVSEs-AVG of the 12 D-EVSEs.

TABLE 10. Average D-EVSEs' profit (in CAN$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	366.7	367.5	380.6	349.5
7 a.m. - 11 a.m.	2024.0	2035.4	1945.2	2008.4
11 a.m. - 5 p.m.	856.4	1217.6	772.0	827.2
5 p.m. - 7 p.m.	8.5	14.2	10.4	11.3
7 p.m. - 12 a.m.	0.0	0.0	4.1	0.8

compared to other D-EVSEs except at the beginning of its operation (6 a.m. - 7 a.m.).

The average total profit comparing all D-EVSEs is shown in Table 10. The D-EVSEs' profit begins to decrease from 1 p.m. to 7 p.m. After 7 p.m., the profit for each hour is meagre; in some cases, such as for D-EVSE-1 and D-EVSE-2, the profit is zero. As mentioned previously, the profit rate decreases due to the low EV arrival rate with their accompanying power demand.

As mentioned previously, D-EVSE-2 and D-EVSE-1 obtained the highest profit compared to other D-EVSEs because of the RESs' power contribution to the D-EVSE-2 and D-EVSE-1 as shown in Table 11 and Table 9.. Also,

TABLE 11. Comparison of the purchased power for D-EVSEs 1 - 3 and D-EVSEs-AVG.

	RESs	Power grid	EV Discharging power
D-EVSE- 1	68%	29%	3%
D-EVSE- 2	60%	32%	7%
D-EVSE- 3	78%	17%	4%
D-EVSE- AVG	72%	23%	5%

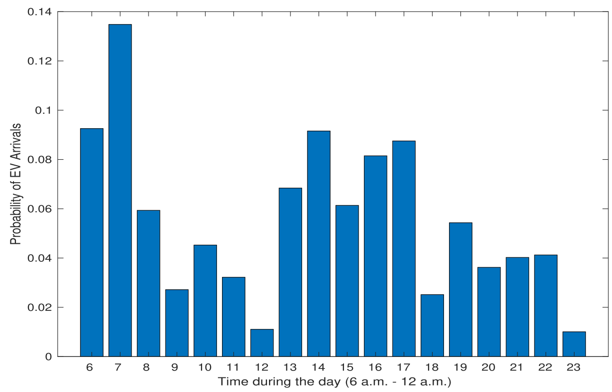

FIGURE 8. EV arrival rates with homogeneous poisson processes.

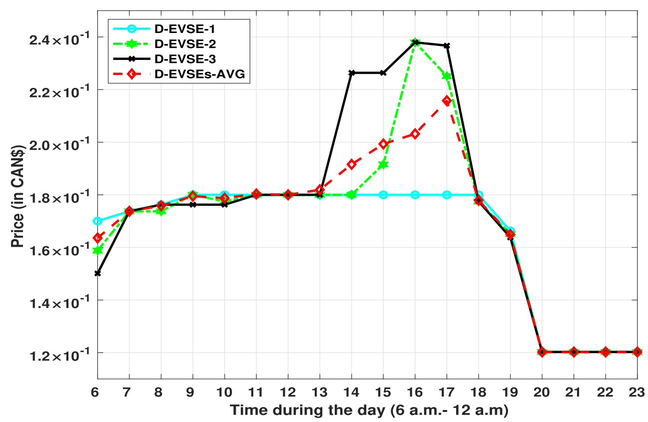

FIGURE 9. Average of the D-EVSEs' diverse charging price comparison for D-EVSEs 1 - 3 with D-EVSEs-AVG of the 12 D-EVSEs.

the EV discharging processes contributed more than 3%, 4%, 5%, and 7% for D-EVSE-1, D-EVSE-3, D-EVSEs-AVG, and D-EVSE-3, respectively.

C. EV ARRIVAL RATES WITH HOMOGENEOUS POISSON PROCESSES

The EV arrival rates are based on homogeneous Poisson processes [56], [57]. The EV arrival probability rate is shown in Figure. 8.

From 9 a.m. to 1 p.m., the average charging prices for all D-EVSEs is almost completely dependent on RESs' price, as shown in Figure 9. However, from 1 p.m. to 6 p.m., all D-EVSEs (with the exception of D-EVSE-1) show that the power price between RESs' price and power grid price is slightly higher than the RESs' price. All D-EVSEs

TABLE 12. Average D-EVSEs' charging price (in CAN$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	1.700×10^{-1}	1.588×10^{-1}	1.501×10^{-1}	1.636×10^{-1}
7 a.m. - 11 a.m.	1.780×10^{-1}	1.770×10^{-1}	1.765×10^{-1}	1.776×10^{-1}
11 a.m. - 5 p.m.	1.800×10^{-1}	1.991×10^{-1}	2.146×10^{-1}	1.953×10^{-1}
5 p.m. - 7 p.m.	1.731×10^{-1}	1.713×10^{-1}	1.706×10^{-1}	1.714×10^{-1}
7 p.m. - 12 a.m.	1.203×10^{-1}	1.203×10^{-1}	1.203×10^{-1}	1.203×10^{-1}

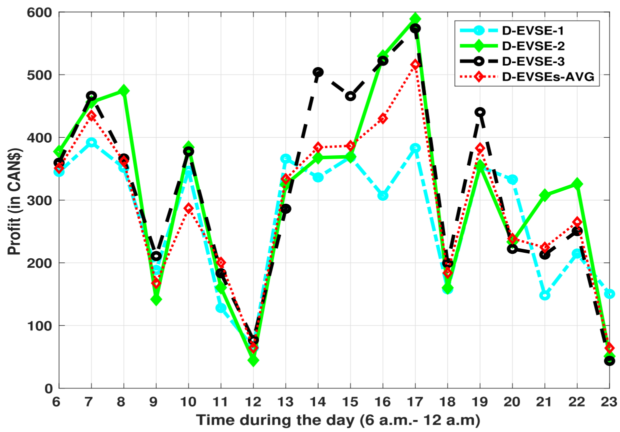

FIGURE 10. Average of the D-EVSEs' profits comparing D-EVSEs 1 - 3 with D-EVSE- AVG of the 12 D-EVSEs.

are reliant on the power grid prices from 6 p.m. to 12 p.m. The red curve (D-EVSEs-AVG) demonstrates that the D-EVSEs-AVG charging price is less than the D-EVSE-3 (black curve) from 1 p.m. to 6 p.m.

Table 12 demonstrates that the charging prices from (6 a.m. - 7 a.m.) for D-EVSE-1 and D-EVSEs-AVG are close to RESs' price while the charging prices for D-EVSE-2 and D-EVSE-3 are shared between the RESs' price and the power grid price. However, from (7 a.m. - 11 a.m.), which is mid-peak, the charging price for all D-EVSEs is close to the RESs' price. By observing Table 12, we can see that from 5 p.m. to 7 p.m., the average charging prices for D-EVSE-2 and D-EVSE-3 as well as D-EVSEs-AVG are less than the charging prices at mid-peak of 17.25 cents in CAN$/kW. This means that these three D-EVSEs accept more EV discharging processes than D-EVSE-1. In contrast, all D-EVSEs from 7 p.m. to 12 a.m. are based on the power grid's price.

As shown in Figure. 10 the D-EVSE-3 and D-EVSE-2 profits (black and green curves) are higher than the other curves. However, the D-EVSEs-AVG gained more profit than D-EVSE-1 except at the end of its operation time from 7 p.m. to 12 a.m.

As shown in Table 13, D-EVSE-2, D-EVSE-3, and D-EVSEs-AVG obtained more profit than D-EVSE-1 from 6 a.m. to 7 p.m. while D-EVSE-1 gained more profit than the other D-EVSEs from 7 p.m. to 12 a.m. From 7 a.m. to 5 p.m., we notice that D-EVSE-2 gained more than 20%, 5%, and 12% profit compared to D-EVSE-1, D-EVSE-2, and D-EVSEs-AVG respectively.

TABLE 13. Average D-EVSEs' profit (in CAN$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	345.0	377.5	359.6	351.0
7 a.m. - 11 a.m.	1407.2	1617.3	1604.5	1451.7
11 a.m. - 5 p.m.	1826.1	2225.0	2429.1	2115.5
5 p.m. - 7 p.m.	511.0	514.8	639.9	566.7
7 p.m. - 12 a.m.	846.3	917.9	729.6	792.2

TABLE 14. Comparison of the purchased power for D-EVSEs 1 - 3 and D-EVSEs-AVG.

	RESs	Power grid	EV Discharging power
D-EVSE- 1	72%	27%	1%
D-EVSE- 2	51%	47%	2%
D-EVSE- 3	41%	57%	2%
D-EVSE- AVG	57%	41%	2%

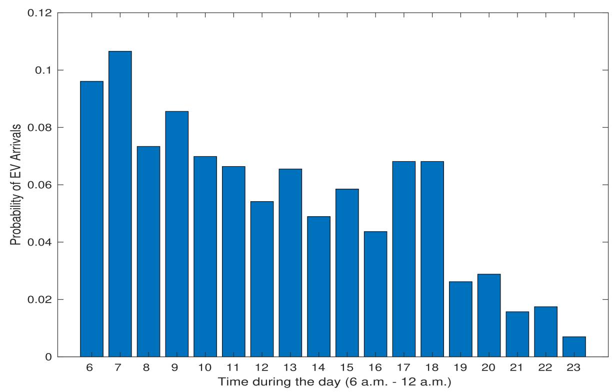

FIGURE 11. EV arrival rates with non-homogeneous poisson processes - case (1).

Table 14 illustrated that D-EVSE-1, D-EVSE-2 and D-EVSEs-AVG obtained 72%, 51% and 57% respectively RESs power more than D-EVSE-3 which obtained 41% RESs power and the 57% power from the power grid. Also, the EVs' discharging power contributes more than 2% in all D-EVSEs except D-EVSE-1, which is 1%.

D. EV ARRIVAL RATES WITH NON-HOMOGENEOUS POISSON PROCESSES INTENSITY - CASE (1)

In this subsection, the EV arrival rates are modelled as a non-homogeneous poisson processes intensity [58]. The probability of EV arrival rate is as shown in Figure. 11.

Figure. 12 shows that all D-EVSEs share the price between RESs and the power grid from 6 a.m. to 10 a.m. However, from 10 a.m. to 5 p.m., the average charging price in D-EVSEs-AVG is less than the average charging prices for

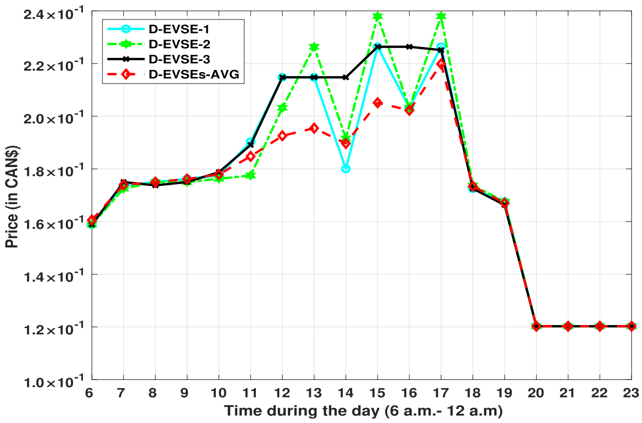

FIGURE 12. Average of the D-EVSEs' diversity charging price comparison for D-EVSE 1 - 3 with D-EVSEs-AVG of the 12 D-EVSEs.

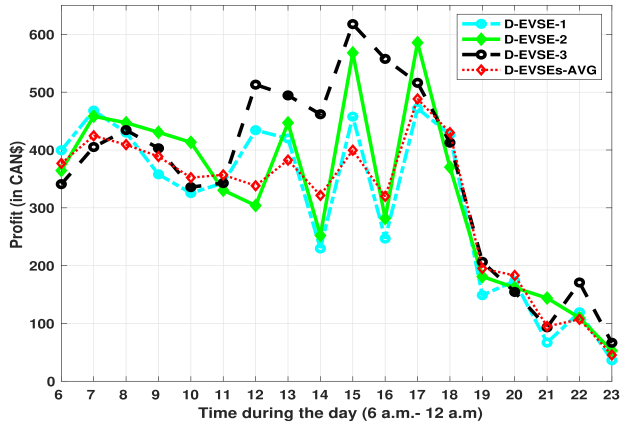

FIGURE 13. Average of the D-EVSEs' profits comparing D-EVSEs 1 - 3 with D-EVSEs-AVG of the 12 D-EVSEs.

TABLE 15. Average D-EVSEs' charging price (in CAN$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	1.588×10^{-1}	1.588×10^{-1}	1.588×10^{-1}	1.606×10^{-1}
7 a.m. - 11 a.m.	1.786×10^{-1}	1.753×10^{-1}	1.783×10^{-1}	1.776×10^{-1}
11 a.m. - 5 p.m.	2.109×10^{-1}	2.167×10^{-1}	2.204×10^{-1}	2.008×10^{-1}
5 p.m. - 7 p.m.	1.700×10^{-1}	1.706×10^{-1}	1.694×10^{-1}	1.702×10^{-1}
7 p.m. - 12 a.m.	1.203×10^{-1}	1.203×10^{-1}	1.203×10^{-1}	1.203×10^{-1}

D-EVSEs (1 to 3). This means that the D-EVSEs-AVG is dependent on the RESs' price. The price of all D-EVSEs decreases and is most likely dependent on the power grid price from 5 p.m. to midnight.

The D-EVSEs-AVG charging price at the time (6 a.m. to 7 a.m.) and (11 a.m. to 5 p.m.) is less than the charging price of D-EVSE-1, D-EVSE-2, and D-EVSE-3. This means that the D-EVSEs-AVG is more reliant on the RESs than the other D-EVSEs as shown in Table 15. From (7 a.m. to 11 a.m.), all D-EVSEs are most likely dependent on RESs. As we see in the same table, the EV discharging processes contribute power, and the D-EVSEs' charging prices are less than the power grid's price at the time (5 p.m. to 7 p.m.).

Figure. 13 shows that the profit obtained by D-EVSE-3 (black curve) is higher than the profit obtained by the other D-EVSEs from 11 a.m. to 4 p.m. In addition, the profit obtained by D-EVSE-2 (green curve) is higher than the profit obtained by the other D-EVSEs from 7 a.m. to 10 a.m. The profit begins dropping at 5 p.m. for all D-EVSEs and especially after 7 p.m..

Table 16 shows that D-EVSE-3 and D-EVSEs-AVG obtained more profit than D-EVSE-1 and D-EVSE-2 at the beginning of the operation time. However, D-EVSE-3 gained more profit than the other D-EVESs at all times except from 11 a.m. to 5 p.m. Between 11 a.m. to 5 p.m., D-EVSE-1 gained more profit than other D-EVSEs. We notice that D-EVSEs-AVG and D-EVSE-3 obtained higher profit than D-EVSE-1 and D-EVSE-2 from 5 p.m. to 12 a.m.

TABLE 16. Average D-EVSEs' profit (in CAN$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	166.40	198.40	223.97	201.29
7 a.m. - 11 a.m.	918.90	782.89	925.70	761.69
11 a.m. - 5 p.m.	949.90	897.33	847.87	776.34
5 p.m. - 7 p.m.	120.17	133.40	176.40	147.30
7 p.m. - 12 a.m.	134.15	131.48	165.73	150.27

TABLE 17. Comparison of the purchased power for D-EVSEs 1 - 3 and D-EVSEs-AVG.

	RESs	Power grid	EV Discharging power
D-EVSE- 1	55%	40%	5%
D-EVSE- 2	46%	52%	2%
D-EVSE- 3	44%	53%	3%
D-EVSE- AVG	59%	38%	3%

D-EVSEs-AVG and D-EVSE-1 obtained more than 59% and 55% RESs' power respectively while D-EVSE-2 and D-EVSE-3 relied on the power grid and obtained 52% and 53% respectively as demonstrated in Table 17. The same table shows that the EVs' discharging power contributed more than 3% to all D-EVSEs with the exception of contributing approximately 2% to D-EVSE-2.

E. EV ARRIVAL RATES WITH NON-HOMOGENEOUS POISSON PROCESSES INTENSITY - CASE (2)

The EV arrival rates are modelled as a non-homogeneous Poisson process with intensity [58]. The probability of EV arrival rates is presented in Figure. 14.

We can observe in Figure 15 that the EV charging price from 7 a.m. to 10 a.m. is similar for all D-EVSEs. The D-EVSE-2 is dependent on RESs' price at the time

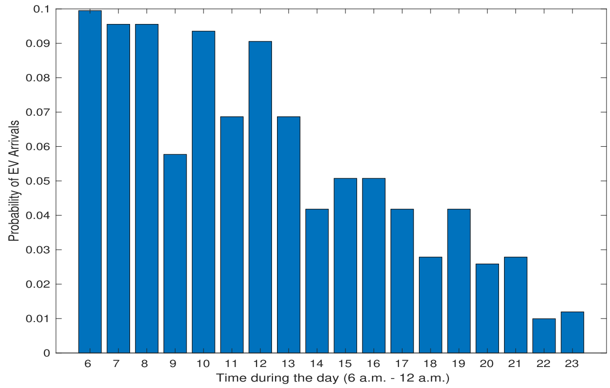

FIGURE 14. EV arrival rates with non-homogeneous poisson processes - case (2).

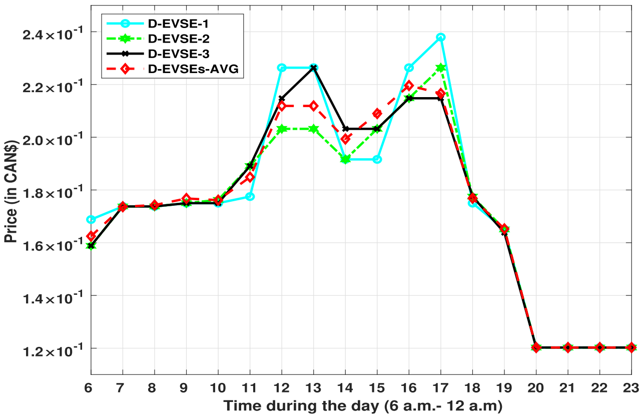

FIGURE 15. Average of the D-EVSEs' diverse charging price comparing D-EVSEs 1 - 3 with D-EVSEs-AVG of the 12 D-EVSEs.

TABLE 18. Average D-EVSEs' charging price (in CAN$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	1.688×10^{-1}	1.588×10^{-1}	1.588×10^{-1}	1.625×10^{-1}
7 a.m. - 11 a.m.	1.750×10^{-1}	1.776×10^{-1}	1.773×10^{-1}	1.771×10^{-1}
11 a.m. - 5 p.m.	2.167×10^{-1}	2.070×10^{-1}	2.128×10^{-1}	2.114×10^{-1}
5 p.m. - 7 p.m.	1.700×10^{-1}	1.713×10^{-1}	1.706×10^{-1}	1.711×10^{-1}
7 p.m. - 12 a.m.	1.203×10^{-1}	1.203×10^{-1}	1.203×10^{-1}	1.203×10^{-1}

(12 p.m. to 2 p.m.) while the D-EVSE-1 is most likely dependent on the power grid's price more specifically between (12 p.m. to 1 p.m.). The D-EVSEs-AVG charging price is the highest among the other D-EVSEs at 9 a.m. and 3 p.m. As shown in Figure 15, the EV discharging power also influences the EV charging price from 6 p.m. to 7 p.m.

Table 18 shows that D-EVSE-2, D-EVSE-3, and D-EVSEs-AVG charging prices are close to RESs' price while D-EVSE-1 is close to the power grid's price from 7 a.m. to 11 a.m. D-EVES-2 charging price is 20.70 cents in CAN$/kW. This means that D-EVES-2 relies on both

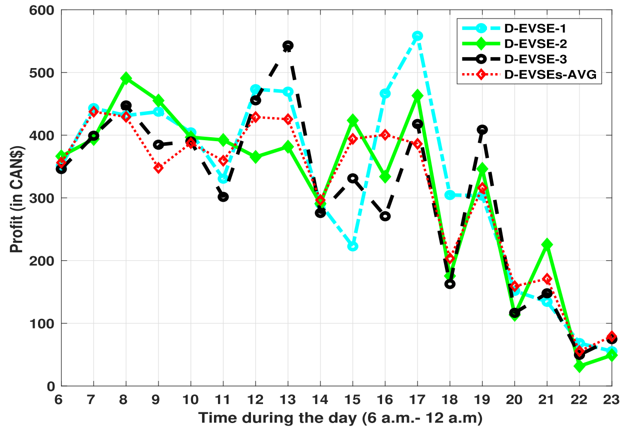

FIGURE 16. Average of the D-EVSEs' profits comparing D-EVSEs 1 - 3 with D-EVSEs-AVG of the 12 D-EVSEs.

TABLE 19. Average D-EVSEs profit (in CAN$).

	D-EVSE 1	D-EVSE 2	D-EVSE 3	D-EVSEs AVG
6 a.m. - 7 a.m.	351.2	366.4	346.0	356.2
7 a.m. - 11 a.m.	2047.1	2129.0	1923.0	1961.2
11 a.m. - 5 p.m.	2480.8	2258.3	2294.4	2331.9
5 p.m. - 7 p.m.	608.2	521.8	571.5	519.6
7 p.m. - 12 a.m.	410.0	420.0	389.0	465.2

the RESs' price and the power grid price but more on the RESs' price. Furthermore, all D-EVSEs' prices from 5 p.m. to 7 p.m. indicate that the EV discharged price contributes to all D-EVSEs. The same table also presents that all D-EVSEs' charging prices from 8 p.m. to 12 a.m. are dependent on the power grid price.

As shown in Figure. 16, D-EVSE-2 presents the highest profit compared to other D-EVSEs from 8 a.m. to 10 a.m. while the D-EVSEs-AVG is the lowest. D-EVSE-3 obtains the highest profit at 1 p.m. and 7 p.m. and the lowest profit at 11 a.m., 4 p.m., and 6 p.m. In contrast, D-EVSE-1 obtained the highest profit compared to other D-EVSEs at 7 a.m. and 12 p.m. and from 4 p.m. to 6 p.m.

Table 19 presents the total average D-EVSEs' profit. D-EVSE-1 and D-EVSE-2 obtain more profit than D-EVSE-3 and D-EVSEs-AVG at the time (7 a.m. – 11 a.m.). From 11 a.m. to 5 p.m., D-EVSE-1 and D-EVSEs-AVG obtain the highest profit compared to D-EVSE-2 and D-EVSE-3. As we can see from the same table, the least profitable D-EVSE from (7 a.m. - 5 p.m.) is D-EVSE-3, while the most profitable is D-EVSEs-AVG.

In Table 20,, the RESs' power contributes more than 49% to all D-EVSEs with the exception of contributing more than 45% to D-EVSE-3. However, D-EVSE-1 is less than 50%, but the purchasing power from the power grid is 48%. D-EVSE-3 obtained 45% from the total sold power and 53% from the

TABLE 20. Comparing the purchased power for D-EVSEs 1 - 3 and D-EVSEs-AVG.

	RESs	Power grid	EV Discharging power
D-EVSE- 1	49%	48%	3%
D-EVSE- 2	55%	41%	4%
D-EVSE- 3	45%	53%	2%
D-EVSE- AVG	54%	43%	3%

power grid. Furthermore, the EVs' discharging power contributes more than 3% to all D-EVSEs, with the exception of contributing 2% to D-EVSE-3.

According to D-EVSEs' profit figures, when EV charging demands are high and the amount of RESs' energy production is high, the profit increases accordingly. As demonstrated in all figures and tables, RESs are profitable and mitigate the power grid's power load. Moreover, RESs make a significant contribution to the D-EVSEs' profit and charging price. Furthermore, the EV discharging power and price contribute to the EV charging price; however, due to this study's aim, which is maximizing the D-EVSE profit, the priority is to reserve the plug-in sockets for charging processes. These results prove that the D-EVSE with our proposed decentralized profit maximization algorithm (DPMA) can maximize its profits more efficiently and manage the EV charging process more effectively. It can also efficiently manage the connection between the D-EVSE and the power grid while taking into account the D-EVSEs' sustainability.

V. CONCLUSION

In this paper, we have proposed a Decentralized Profit Maximization Algorithm (DPMA) aiming to optimize the D-EVSEs' profits. Solar energy was the primary power source for the D-EVSE, while D-EVSE has a reciprocal link to the power grid. D-EVSEs manage the reciprocal link for the power grid's requisition between D-EVSE and the power grid. The DPMA helps D-EVSEs maximize their profit from the electricity price variation during the day when selling or buying electricity respectively to EVs or from the grid and EV as discharged power processes. Moreover, renewable energy production reduces the power load on the power grid. For D-EVSEs' charging prices and profits, we presented a comparative study between different D-EVSEs.

The proposed model maximized D-EVSE profits significantly in all different scenarios and showed that the RESs are more profitable than the power grid for D-EVSE. Five EV arrival rate scenarios were considered to investigate the efficiency of our proposed model. Simulation results conducted to validate the proposed algorithm demonstrated its effectiveness while satisfying the defined constraints. In future work, we plan to extend our proposed model and test using other RESs such as wind turbines to help the D-EVSE lower its dependency on the power grid. Also, we plan to add battery depth of discharge and battery time to live parameters to test the proposed model. Moreover, the game-theoretic approach will be applied to future work to maximize the D-EVSEs' profit and also minimize the EVs' charging cost.

REFERENCES

[1] U. S. Environmental Protection Agency. (2019). *Centralized Generation of Electricity and its Impacts on the Environment*. Accessed: Oct. 2020. [Online]. Available: https://bit.ly/3jcW5fX

[2] T. Chen, X. Zhang, J. Wang, J. Li, C. Wu, M. Hu, and H. Bian, "A review on electric vehicle charging infrastructure development in the UK," *J. Modern Power Syst. Clean Energy*, vol. 8, no. 2, pp. 193–205, 2020.

[3] Y. P. T. F. the Environment. (Feb. 2020). *Ban on Petrol and Diesel Cars Brought Forward*. Accessed: Feb. 2020. [Online]. Available: https://ypte.org.uk/news/ban-on-petrol-and-diesel-cars-brought-forward

[4] G. L. Authority. (Feb. 2020). *Driving Away From Diesel Reducing Air Pollution From Diesel Vehicles*. Accessed: Feb. 2020. [Online]. Available: https://bit.ly/2YxpJoy

[5] Government of Canada—Transport Canada. (Aug. 2019). *Zero-Emission Vehicles Program*. Accessed: Mar. 2020. [Online]. Available: http://bit.ly/2VJvI9n

[6] M. Latifi, A. Rastegarnia, A. Khalili, and S. Sanei, "Agent-based decentralized optimal charging strategy for plug-in electric vehicles," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 3668–3680, May 2019.

[7] The National Renewable Energy Laboratory-U.S. Department of Energy. (2019). *From the Bottom Up: Designing a Decentralized Power System*. Accessed: Oct. 2020. [Online]. Available: https://bit.ly/2FHwkXi

[8] Natural Resources Canada—Government of Canada. (2018). *SMART GRID IN CANADA*. Accessed: Oct. 2020. [Online]. Available: https://bit.ly/35biLZ6

[9] S. M. Shariff, M. S. Alam, F. Ahmad, Y. Rafat, M. S. J. Asghar, and S. Khan, "System design and realization of a solar-powered electric vehicle charging station," *IEEE Syst. J.*, vol. 14, no. 2, pp. 2748–2758, Jun. 2019.

[10] Y. Zhang, Y. Wang, F. Li, B. Wu, Y.-Y. Chiang, and X. Zhang, "Efficient deployment of electric vehicle charging infrastructure: Simultaneous optimization of charging station placement and charging pile assignment," *IEEE Trans. Intell. Transp. Syst.*, early access, May 7, 2020, doi: 10.1109/TITS.2020.2990694.

[11] M. E. Kabir, C. Assi, H. Alameddine, J. Antoun, and J. Yan, "Demand-aware provisioning of electric vehicles fast charging infrastructure," *IEEE Trans. Veh. Technol.*, vol. 69, no. 7, pp. 6952–6963, Jul. 2020.

[12] Y. Zhao, Y. Guo, Q. Guo, H. Zhang, and H. Sun, "Deployment of the electric vehicle charging station considering existing competitors," *IEEE Trans. Smart Grid*, vol. 11, no. 5, pp. 4236–4248, Sep. 2020.

[13] S. Alshahrani, M. Khalid, and M. Almuhaini, "Electric vehicles beyond energy storage and modern power networks: Challenges and applications," *IEEE Access*, vol. 7, pp. 99031–99064, 2019.

[14] X. Li, Y. Xiang, L. Lyu, C. Ji, Q. Zhang, F. Teng, and Y. Liu, "Price incentive-based charging navigation strategy for electric vehicles," *IEEE Trans. Ind. Appl.*, vol. 56, no. 5, pp. 5762–5774, Oct. 2020.

[15] C. Fang, H. Lu, Y. Hong, S. Liu, and J. Chang, "Dynamic pricing for electric vehicle extreme fast charging," *IEEE Trans. Intell. Transp. Syst.*, vol. 22, no. 1, pp. 531–541, Jan. 2020.

[16] S. Zhou, W. Gu, Y. Qiu, F. Zou, D. He, P. Yu, J. Du, X. Luo, C. Wang, and Z. Wu, "Dynamic EV charging pricing methodology for facilitating renewable energy with consideration of highway traffic flow," *IEEE Access*, vol. 8, pp. 13161–13178, 2020.

[17] Y. Zheng, J. Luo, X. Yang, and Y. Yang, "Intelligent regulation on demand response for electric vehicle charging: A dynamic game method," *IEEE Access*, vol. 8, pp. 66105–66115, 2020.

[18] F. Eldali and S. Suryanarayanan, "A data-driven justification for dedicated dynamic pricing for residences-based plug-in electric vehicles in wind energy-rich electricity grids," *IEEE Open Access J. Power Energy*, vol. 7, pp. 51–58, 2020.

[19] M. B. Rasheed, M. Awais, T. Alquthami, and 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.

[20] Y. Zhang, P. You, and L. Cai, "Optimal charging scheduling by pricing for EV charging station with dual charging modes," *IEEE Trans. Intell. Transp. Syst.*, vol. 20, no. 9, pp. 3386–3396, Sep. 2019.

[21] D. Said, S. Cherkaoui, and L. Khoukhi, "Guidance model for EV charging service," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2015, pp. 5765–5770.

[22] D. Said and H. T. Mouftah, "A novel electric vehicles charging/discharging scheme with load management protocol," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2017, pp. 1–6.

[23] T. G. Alghamdi, D. Said, and H. T. Mouftah, "Decentralized electric vehicle supply stations (D-EVSSs): A realistic scenario for smart cities," *IEEE Access*, vol. 7, pp. 63016–63026, 2019.

[24] R. Rana, S. Prakash, and S. Mishra, "Energy management of electric vehicle integrated home in a time-of-day regime," *IEEE Trans. Transport. Electrific.*, vol. 4, no. 3, pp. 804–816, Sep. 2018.

[25] D. Said and H. T. Mouftah, "A novel electric vehicles charging/discharging management protocol based on queuing model," *IEEE Trans. Intell. Vehicles*, vol. 5, no. 1, pp. 100–111, Mar. 2020.

[26] Q. Yan, B. Zhang, and M. Kezunovic, "Optimized operational cost reduction for an EV charging station integrated with battery energy storage and PV generation," *IEEE Trans. Smart Grid*, vol. 10, no. 2, pp. 2096–2106, Mar. 2019.

[27] M. Carrion, "Determination of the selling price offered by electricity suppliers to electric vehicle users," *IEEE Trans. Smart Grid*, vol. 10, no. 6, pp. 6655–6666, Nov. 2019.

[28] H. Ren, A. Zhang, H. Zhao, X. Yan, J. Lu, and W. Li, "Impact analysis of electric vehicle price mechanism on load demand response of distribution network," in *Proc. IEEE PES Innov. Smart Grid Technol. Eur. (ISGT-Eur.)*, Sep. 2019, pp. 1–5.

[29] M. A. Tajeddini, H. Kebriaei, and L. Glielmo, "Decentralized charging coordination of plug-in electric vehicles based on reverse Stackelberg game," in *Proc. 18th Eur. Control Conf. (ECC)*, Jun. 2019, pp. 3414–3419.

[30] L. Park, S. Jeong, D. S. Lakew, J. Kim, and S. Cho, "New challenges of wireless power transfer and secured billing for Internet of electric vehicles," *IEEE Commun. Mag.*, vol. 57, no. 3, pp. 118–124, Mar. 2019.

[31] W. Alharbi and K. Bhattacharya, "Flexibility provisions from a fast charging facility equipped with DERs for wind integrated grids," *IEEE Trans. Sustain. Energy*, vol. 10, no. 3, pp. 1006–1014, Jul. 2019.

[32] M. A. Tajeddini and H. Kebriaei, "A mean-field game method for decentralized charging coordination of a large population of plug-in electric vehicles," *IEEE Syst. J.*, vol. 13, no. 1, pp. 854–863, Mar. 2019.

[33] A. S. Bin Humayd and K. Bhattacharya, "Design of optimal incentives for smart charging considering utility-customer interactions and distribution systems impact," *IEEE Trans. Smart Grid*, vol. 10, no. 2, pp. 1521–1531, Mar. 2019.

[34] V. Lakshminarayanan, V. G. S. Chemudupati, S. K. Pramanick, and K. Rajashekara, "Real-time optimal energy management controller for electric vehicle integration in workplace microgrid," *IEEE Trans. Transport. Electrific.*, vol. 5, no. 1, pp. 174–185, Mar. 2019.

[35] M. Shokri and H. Kebriaei, "Mean field optimal energy management of plug-in hybrid electric vehicles," *IEEE Trans. Veh. Technol.*, vol. 68, no. 1, pp. 113–120, Jan. 2019.

[36] Z. Ding, Y. Lu, L. Zhang, W.-J. Lee, and D. Chen, "A stochastic resource-planning scheme for PHEV charging station considering energy portfolio optimization and price-responsive demand," *IEEE Trans. Ind. Appl.*, vol. 54, no. 6, pp. 5590–5598, Nov. 2018.

[37] W. Jiang and Y. Zhen, "A real-time EV charging scheduling for parking lots with PV system and energy store system," *IEEE Access*, vol. 7, pp. 86184–86193, 2019.

[38] Y. Wang and J. S. Thompson, "Two-stage admission and scheduling mechanism for electric vehicle charging," *IEEE Trans. Smart Grid*, vol. 10, no. 3, pp. 2650–2660, May 2019.

[39] A. Ghosh and V. Aggarwal, "Menu-based pricing for charging of electric vehicles with vehicle-to-grid service," *IEEE Trans. Veh. Technol.*, vol. 67, no. 11, pp. 10268–10280, Nov. 2018.

[40] A. Ghosh and V. Aggarwal, "Control of charging of electric vehicles through menu-based pricing," *IEEE Trans. Smart Grid*, vol. 9, no. 6, pp. 5918–5929, Nov. 2018.

[41] X. Yang, Y. Zhang, H. Wu, and H. He, "An event-driven ADR approach for residential energy resources in microgrids with uncertainties," *IEEE Trans. Ind. Electron.*, vol. 66, no. 7, pp. 5275–5288, Jul. 2019.

[42] A. Verma and B. Singh, "An implementation of renewable energy based grid interactive charging station," in *Proc. IEEE Transp. Electrific. Conf. Expo (ITEC)*, Jun. 2019, pp. 1–6.

[43] Y. Sun, Z. Chen, Z. Li, W. Tian, and M. Shahidehpour, "EV charging schedule in coupled constrained networks of transportation and power system," *IEEE Trans. Smart Grid*, vol. 10, no. 5, pp. 4706–4716, Sep. 2019.

[44] B. Ramachandran, S. K. Srivastava, C. S. Edrington, and D. A. Cartes, "An intelligent auction scheme for smart grid market using a hybrid immune algorithm," *IEEE Trans. Ind. Electron.*, vol. 58, no. 10, pp. 4603–4612, Oct. 2011.

[45] B. P. Majumder, M. N. Faqiry, S. Das, and A. Pahwa, "An efficient iterative double auction for energy trading in microgrids," in *Proc. IEEE Symp. Comput. Intell. Appl. Smart Grid (CIASG)*, Dec. 2014, pp. 1–7.

[46] Y. Wang, W. Saad, Z. Han, H. V. Poor, and T. Basar, "A game-theoretic approach to energy trading in the smart grid," *IEEE Trans. Smart Grid*, vol. 5, no. 3, pp. 1439–1450, May 2014.

[47] Proterra. (Jan. 2021). *Charging For Electric Fleets*. Accessed: Feb. 2021. [Online]. Available: https://www.proterra.com/energy-services/charging-infrastructure/

[48] T. G. Alghamdi, D. Said, and H. T. Mouftah, "Decentralized energy storage system for EVs charging and discharging in smart cities context," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2019, pp. 1–5.

[49] T. G. Alghamdi, D. Said, and H. T. Mouftah, "Decentralized game-theoretic scheme for D-EVSE based on renewable energy in smart cities: A realistic scenario," *IEEE Access*, vol. 8, pp. 48274–48284, 2020.

[50] I. Canada. (Mar. 2020). *Electric Vehicle Home and Workplace Charging Study*. Accessed: Jan. 2021. [Online]. Available: https://bit.ly/3s70rL0

[51] T. G. Alghamdi, D. Said, and H. T. Mouftah, "Decentralized game-theoretic approach for D-EVSE based on renewable energy in smart cities," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Jun. 2020, pp. 1–6.

[52] Hydro Ottawa, Ottawa, Canada. (Dec. 2020). *Time-of-Use Rates*. Accessed: Dec. 2020. [Online]. Available: http://bit.ly/2LbK3IA

[53] Z. Wang, P. Jochem, and W. Fichtner, "A scenario-based stochastic optimization model for charging scheduling of electric vehicles under uncertainties of vehicle availability and charging demand," *J. Cleaner Prod.*, vol. 254, May 2020, Art. no. 119886. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0959652619347560

[54] S.-N. Yang, W.-S. Cheng, Y.-C. Hsu, C.-H. Gan, and Y.-B. Lin, "Charge scheduling of electric vehicles in highways," *Math. Comput. Model.*, vol. 57, no. 11, pp. 2873–2882, 2013. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0895717711007394

[55] S.-N. Yang, W.-S. Cheng, Y.-C. Hsu, C.-H. Gan, and Y.-B. Lin, "Charge scheduling of electric vehicles in highways through mobile computing," in *Proc. IEEE 17th Int. Conf. Parallel Distrib. Syst.*, Dec. 2011, pp. 692–698.

[56] G. Li and X.-P. Zhang, "Modeling of plug-in hybrid electric vehicle charging demand in probabilistic power flow calculations," *IEEE Trans. Smart Grid*, vol. 3, no. 1, pp. 492–499, Mar. 2012.

[57] M. Alizadeh, A. Scaglione, and Z. Wang, "On the impact of SmartGrid metering infrastructure on load forecasting," in *Proc. 48th Annu. Allerton Conf. Commun., Control, Comput. (Allerton)*, Sep. 2010, pp. 1628–1636.

[58] M. Alizadeh, A. Scaglione, J. Davies, and K. S. Kurani, "A scalable stochastic model for the electricity demand of electric and plug-in hybrid vehicles," *IEEE Trans. Smart Grid*, vol. 5, no. 2, pp. 848–860, Mar. 2014.

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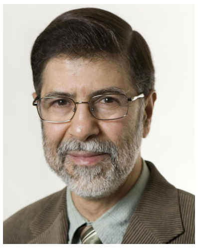

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