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Techno-Economic Analysis of Electric Vehicle Parking Lots in Microgrids

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Abstract — This study aims to analyze the techno-economic utilization of electric vehicle parking lots in microgrids under a considerable penetration of renewable energy resources. For this purpose, an optimization model is proposed considering the investment and maintenance costs of the parking lots as well as the operation and emission costs of microgrids. In the model, natural gas and electricity distribution systems are simulated in a grid-connected microgrid with a considerable share of wind turbines. A scenario generation technique is also utilized to determine the number and arrival state of charge of electric vehicles in parking lots. A microgrid, which consists of a 33-bus electricity system and an 11-node gas system, is studied to investigate the charging and discharging of electric vehicles in parking lots. It concludes that electric vehicles in parking lots offer flexibility that offsets investment costs and reduces the amount of emission. Owing to the flexibility, the natural gas system can also respond the changes in natural gas demand more efficiently due to more natural gas within pipelines.

Keywords — electric vehicles, microgrid, natural gas and electricity systems, techno-economic analysis, electric vehicle parking lots

NOMENCLATURE

Sets

b	Index of bus in electricity system
n	Index of node in gas system
y	Index of injection node in gas system
t	Index of time
k	Index of parking lot
p	Index of pipeline in gas system
l	Index of electric line in electricity system
m	Index of electric vehicles

Parameters

r	Annual rate of return (%)
j	Lifespan (year)
$Demand^{day/year}$	Total energy demand in a day or year (kWh)
$Cost^{pl}$	Cost of investment on a parking lot (\$/kW)
$Cost^{mpl}$	Cost of maintenance for parking lot (\$/kW)
Cap_k	Capacity of parking lot (kW)
$Cost^{gas}$	Cost of purchasing natural gas (\$/cubic meter)
$Cost^{lp}$	Cost of linepack management (\$/cubic meter)
$Cost^{sh}$	Shedding cost (\$/cubic meter)
$Cost^{co2}$	Cost of emission (\$/kW)
$Price_t$	Price of purchasing electricity from main grid (\$/kW)
$Price'_t$	Price of selling electricity to main grid (\$/kW)
α_p	Variable cost of operation (\$/kW)

β_b	Fixed cost of operation (\$)
$Gas_{p,t}^0$	Initial volume of natural gas within pipeline (cubic meter)
R_l	Resistance (ohm)
X_l	Reactance (ohm)
Z_l	Impedance (ohm)
$eff^{ch/dch}$	Efficiency of charge or discharge (%)
$SC_{k,t}^0$	Initial state of charge of parking lot (kWh)
$P_k^{ch/dch min/max}$	Minimum or maximum charged or discharged power (kW)
$SC_{k,t}^{min/max}$	Minimum or maximum state of charge of parking lot (kWh)
Number ^{ev max}	Maximum number of electric vehicles in parking lot
$t^{arv/dep}$	Arrival or departure time of electric vehicles (hour)
σ	Standard deviation
μ	Mean value

Variables

$Cost^{inv}$	Cost of investment (\$)
$Cost^{oper}$	Cost of operation (\$)
$Cost^M$	Cost of maintenance (\$)
$Cost^{CO2}$	Cost of emission (\$)
$Cost^{gas}$	Cost of natural gas system operation (\$)
$Cost^{elec}$	Cost of electricity system operation (\$)
$P_{b,t}$	Output power of generating unit (kW)
$Gas_{y,t}^{buy}$	Purchased volume of natural gas (cubic meter)
$\Delta Gas_{n,t}$	Changes in natural gas volume within pipeline (cubic meter)
$GNS_{n,t}$	Volume of natural gas-not-supplied (cubic meter)
$u_{b,t}$	Status of generating unit {0,1}
$Gas_{n,t}^{pipe}$	Natural gas flow within pipeline (cubic meter/hour)
C	Lacey's equation constant (cubic meter/mbar ^{1/2})
$\mathcal{P}_{n,t}$	Pressure (mbar)
$V_{b,t}$	Voltage magnitude (Volt)
$I_{l,t}$	Current magnitude (Ampere)
$P_{l,t}^{line}$	Active power within line (kW)
$Q_{l,t}^{line}$	Reactive power within line (kVAR)
$SC_{k,t}$	State of charge of parking lot (kWh)
$P_{k,t}^{ch/dch}$	Charged/discharged power (kW)
$\gamma_{k,t}$	Status of charge or discharge {0,1}
$SC_{p,k,t}^{arv/dep}$	State of charge of arrived/departed vehicles to/from parking lot (kWh)
Number ^{ev}	Number of electric vehicles

I. INTRODUCTION

A. Motivation

Moving to supply energy from renewable energy resources has been started due to the benefits, such as not emitting greenhouse emissions [1]. The global target is to supply the total energy demand using zero-emission renewable energy resources by 2050. However, the problem is still the variability of renewable energy resources' output power (e.g., the output power of photovoltaic systems and wind turbines) that is dependent on different parameters, such as weather conditions. A solution would be the deployment of microgrids that can help with the integration of intermittent renewable energy resources [2]. Microgrids are small-scale energy systems, which consist of a group of loads and distributed energy resources (e.g., distributed renewable resources and/or distributed dispatchable units) that works either connected or disconnected (i.e., island mode) to/from the main grid. More precisely, while being connected normally to the main grid to buy and sell electricity from/to, a microgrid can be disconnected and work independently when there is a failure in the upstream grid.

To reach the carbon neutrality targets, the transportation system is another sector that needs to be decarbonized as it contributes to producing a considerable amount of emissions [3]. A solution would be the integration of electric vehicles into modern energy systems, which do not emit carbon dioxide or other harmful pollutants at the point of use. The integration of electric vehicles increases energy demand, which increases also the need to invest in renewable energy resources to supply vehicles without burning fossil fuels and producing emissions. However, a scheduled charging and discharging strategy for electric vehicles would be helpful, as it reduces the peak of energy demand and prevents heavy investment in generation and distribution network expansion [4]. More precisely, the scheduled charging can smooth out the energy demand curve, reducing the need for new renewable and nonrenewable energy generation and network infrastructures to meet peak demand. As the integration of electric vehicles also needs adequate infrastructure, it is of great importance to conduct a techno-economic assessment and examine their impact on energy systems.

B. Literature review

Among previous studies, in [5], the economic feasibility of renewable resources was studied for charging stations of electric vehicles in different locations in China. The results of this study showed that a hybrid system, which, consists of wind turbines, photovoltaic systems, and battery storage systems, is the most effective response to facilitating large-scale integration of electric vehicles into the power system. In [6], [7], the techno-economic feasibility of electric vehicle parking lots coupled with photovoltaic systems was taken into consideration. It concluded that the integration of photovoltaic systems into parking lots reduces the net present cost of parking lots. In [8], a techno-economic study of supply infrastructure for electric vehicles in a microgrid was implemented considering different weather conditions and levels of electric vehicle integration. The output of the study indicated that optimal scheduling of electric vehicles improved the operation of the microgrid. In another study [9], the potential of electric vehicle fleets was studied to provide both active and reactive supply-demand balance. The results of the study also showed voltage profile improvement, released capacity of generating units, and reduction in the cost

of operation. In [10], the role of demand response programs and electric vehicle integration into a microgrid was examined. It concluded that the demand response of electric vehicles integration into the microgrid can provide economic and environmental benefits. In [11], the economic and environmental benefits of electric vehicles with bi-directional chargers were studied in a microgrid. It also concluded that discharging electric vehicles in a scheduled strategy provided economic and environmental through peak shaving. In [12], a techno-economic assessment was conducted to study the role of electric vehicles in a multi-energy microgrid that consists of electricity and hydrogen networks. The output of this study also demonstrated cost savings and ensures less grid reliance. In another study [13], a techno-economic model was developed for the assessment of electric vehicle operation in cold weather conditions. The results of the study indicate the effects of different parameters, such as ambient temperature, on the operation of electric vehicles from different technical and economic points of view.

C. Research gap and contributions

Despite the increasing interest in electric vehicle adoption and the potential for electric vehicle parking lots to provide a convenient and sustainable charging solution, the techno-economic feasibility of electric vehicle parking lots has been under-researched in the literature. Moreover, existing studies have not adequately accounted for the realistic limitations of electricity network infrastructure, which can have a significant impact on the feasibility and cost-effectiveness of electric vehicle parking lots. Some components of the electricity system that are used in conjunction with electric vehicle parking lots, such as distributed dispatchable gas-fired units, are connected to the natural gas system. Therefore, a coordinated operation of these systems can provide significant benefits although this has not been explored in the literature. The research gaps need to be addressed to provide decision-makers with valuable insights to support the development of sustainable and cost-effective electric vehicle charging solutions. The main contributions of this study to fill this gap are discussed in the following.

The main contribution of this paper is the development of an optimization model that integrates the investment and maintenance costs of electric vehicle parking lots and the operation and emission costs of microgrids. The proposed model uses a scenario generation technique to randomly determine the arrival time, departure time, and arrival state of charge of electric vehicles in the parking lots. The model is also extended to consider the natural gas system supplying components in the electricity system, and a case study is conducted on an 11-node natural gas system coupled with a 33-bus electricity system to examine the impact of parking lots on supply-demand provision besides the economic analysis. The microgrid can buy and sell electricity to/from the main grid, and different cases are analyzed, including scheduled and unscheduled charging, various sizes of parking lots, and the absence of parking lots, providing a comprehensive analysis from both technical and economic perspectives.

II. METHODOLOGY

The multi-energy microgrid represented in Fig. 1 is a system that combines natural gas and electricity distribution systems, with gas-fired dispatchable units connecting the systems. The gas-fired units allow for the conversion of

natural gas into electricity and provide a source of power that can be dispatched, or controlled, as needed to meet the demand for energy within the microgrid. The microgrid also includes renewable energy sources, such as wind turbines and photovoltaic systems, and it allows electric vehicles to be charged and discharged at the electric vehicle parking lots.

The mathematical model used for conducting a techno-economic assessment of electric vehicle parking lots in the multi-energy microgrid is based on certain assumptions. For instance, the gas distribution system model uses the continuity and momentum equations to simulate gas flow, with the assumption that variations in kinetic energy due to changes in velocity and density are negligible. In the electricity distribution system's model, the demand during each operating hour is considered constant active and reactive power. Power losses along a branch are assumed at the beginning of that branch, the network is addressed in a single-phase and balanced equivalent, and the microgrid interacts with the main grid in a day-ahead market. It should be noted it is also assumed that the day-ahead electricity market has been operated based on supply and demand, and the price of electricity has been determined by the interaction between electricity suppliers (generators) and consumers (buyers).

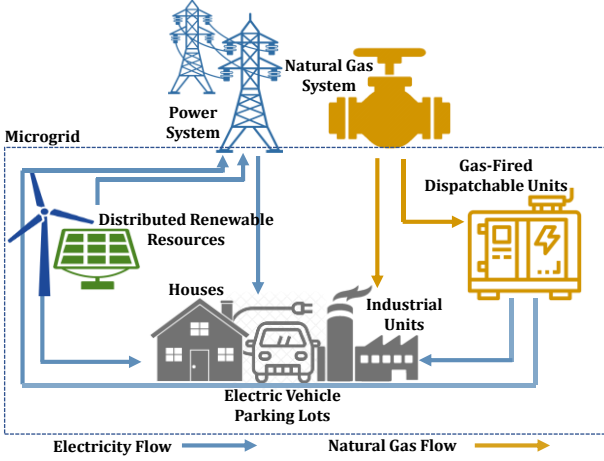


Fig. 1. Illustration of multi-energy microgrid

The model and formulation, including objective function and constraints as well as the scenario generation method for electric vehicles in parking lots and the solving method, are discussed in the following.

A. Optimization problem

The model and formulation for the techno-economic assessment of parking lots with power-to-grid capability are discussed in this section. In (1), the objective function of the optimization problem is discussed, which consists of four terms. The first term indicates the investment costs in a day for the establishment of the electric vehicle parking lots, including infrastructure and equipment. To calculate the cost in a day, the total investment cost is multiplied by $\left[\frac{r(1+r)^j}{(1+r)^j - 1} \right] \cdot \frac{Demand^{day}}{Demand^{year}}$. The second term represents the operation cost of the microgrid consisting of natural gas and electricity systems operating costs. The third term addresses the cost of maintenance for the parking lots in the microgrid. Additionally, the last term demonstrates the fine for producing carbon dioxide (i.e., carbon dioxide emission cost).

$$OF = \left[\frac{r(1+r)^j}{(1+r)^j - 1} \right] \cdot \frac{Demand^{day}}{Demand^{year}} \cdot Cost^{inv} + Cost^{oper} + Cost^M + Cost^{CO2} \quad (1)$$

The total investment cost is appropriate to the capacity of parking lots which is indicated in (2). The operation cost of the microgrid consists of the natural gas distribution system operating cost and the electricity distribution system operating cost, indicated in (3). In (4), the maintenance cost of parking lots is addressed, which is also appropriate to the capacity of parking lots. The cost of carbon dioxide production for dispatchable gas-fired units is also indicated in (5).

$$Cost^{inv} = \sum_{k=1}^K Cost^{pl} \cdot Cap_k \quad (2)$$

$$Cost^{oper} = Cost^{gas} + Cost^{elec} \quad (3)$$

$$Cost^M = \sum_{k=1}^K Cost^{Mpl} \cdot Cap_k \quad (4)$$

$$Cost^{CO2} = \sum_{t=1}^T \sum_{b=1}^B Cost^{CO2} \cdot P_{b,t} \quad (5)$$

In (6)-(7) the operating costs of natural gas and electricity systems are indicated, respectively. The operation cost of the gas system consists of the cost of purchasing natural gas from the main grid, the cost of linepack management, and the cost of gas shedding. It should be noted that the linepack means the amount of natural gas within pipelines, and it may be used to deal with the changes between supply and demand [14]. The operating cost of the electricity system includes the cost of purchased and sold power from/to the main grid as well as the cost of generating power using dispatchable gas-fired units.

$$Cost^{gas} = \sum_{t=1}^T \sum_{y=1}^Y Cost^{Gas} \cdot Gas_{y,t}^{buy} + \sum_{t=1}^T \sum_{n=1}^N Cost^{lp} \cdot \Delta Gas_{n,t} + \sum_{t=1}^T \sum_{y=1}^Y Cost^{sh} \cdot GNS_{n,t} \quad (6)$$

$$Cost^{elec} = \sum_{t=1}^T \sum_{b=1}^B Price_t \cdot P_{b,t}^{buy} - \sum_{t=1}^T \sum_{b=1}^B Price'_t \cdot P_{b,t}^{sell} + \sum_{t=1}^T \sum_{b=1}^B (\alpha_b \cdot P_{b,t} + \beta_b \cdot u_{b,t}) \quad (7)$$

Some constraints are taken into consideration, including natural gas flow balance, active and reactive power flow balance, maximum/minimum gas injection through injection nodes, maximum/minimum purchased electricity from the main grid, maximum/minimum pressure at nodes, maximum/minimum voltage at nodes, and maximum/minimum active and reactive power flow and current within lines in the electricity system.

In addition to the already mentioned constraints, in (8), the changes in linepack within pipelines are demonstrated. In (9), Lacey's equation is indicated which is used to simulate the low-pressure natural gas system by connecting gas flow within pipelines and pressure at nodes [15]. In (10)-(11), Kirchhoff's voltage law is represented that connects voltage and current in the electricity distribution system (i.e., connect active and reactive power) [16].

$$Gas_{p,t} = Gas_{p,t}^0 \quad \forall p \in (n, n'), \forall t \quad (8)$$

$$+ Gas_{p,t-1} + Gas_{n,t}^{pipe} - Gas_{n',t}^{pipe}$$

$$Gas_{p,t}^{pipe} = C \sqrt{P_{n,t} - P_{n',t}} \quad \forall p \in (n, n'), \forall t \quad (9)$$

$$V_{b,t}^2 - V_{b',t}^2 = 2(R_l \cdot P_{l,t}^{line} + X_l \cdot Q_{l,t}^{line}) + Z_l^2 \cdot I_{l,t}^2 \quad l \in (b, b'), \forall t \quad (10)$$

$$V_{b,t}^2 \cdot I_{l,t}^2 = Q_{l,t}^{line 2} + P_{l,t}^{line 2} \quad l \in (b, b'), \forall t \quad (11)$$

In the following, some constraints are discussed, related to the operation of electric vehicles' parking lots. The state of charge of electric vehicle parking lots is indicated in (12). It is calculated considering the state of charge in the previous hour, the state of charge of arrived and departed electric vehicles, and charging and discharging the energy of the vehicle parking lots considering the efficiency of charge and discharge. Charged and discharged power of electric vehicles' parking lots are limited in (13)-(16). A binary variable is also determined to avoid the charge and discharge of a parking lot at the same time (i.e., from a parking lot to the distribution system or vice versa). The state of charge of electric vehicle parking lots is also limited to prevent overcharging or undercharging of vehicles' batteries (17).

$$SC_{k,t} = SC_{k,t}^0 + SC_{k,t-1} + \sum_p (SC_{p,k,t}^{arr} - SC_{p,k,t}^{dep}) + (eff^{ch} \cdot P_{k,t}^{ch} - P_{k,t}^{dch} / eff^{dch}) \quad \forall k, \forall t \quad (12)$$

$$P_{k,t}^{ch} \leq P_k^{ch \max} \cdot y_{k,t} \quad \forall k, \forall t \quad (13)$$

$$P_{k,t}^{ch} \geq P_k^{ch \min} \cdot y_{k,t} \quad \forall k, \forall t \quad (14)$$

$$P_{k,t}^{dch} \leq P_k^{dch \max} \cdot (1 - y_{k,t}) \quad \forall k, \forall t \quad (15)$$

$$P_{k,t}^{dch} \geq P_k^{dch \min} \cdot (1 - y_{k,t}) \quad \forall k, \forall t \quad (16)$$

$$SC_k^{\min} \leq SC_{k,t} \leq SC_k^{\max} \quad \forall k, \forall t \quad (17)$$

B. Scenario generation

It should be noted that, in this model, it is assumed that a contract is signed between electric vehicles and parking lot owners to allow vehicle-to-grid. To study the problem, a scenario is required, which represents the hourly state of charge of electric vehicles in each parking lot. For this purpose, the Gaussian Distribution Function is utilized to generate the scenario for the arrival time of electric vehicles as well as the state of charge at arrival, represented in (18) [17]. It is noteworthy to mention that time of departure should be greater than the time of arrival in the scenario generation (19). The number of electric vehicles is also limited according to the capacity of parking lots (20). Considering the capacity of parking lots, the maximum/minimum state of charge and charging/discharging power of parking lots are limited (21)-(22).

$$f(x, \mu, \sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (18)$$

$$t^{arr} \leq t^{dep} \quad (19)$$

$$Number^{ev} \leq Number^{ev \max} \quad (20)$$

$$SOC_{k,t}^{\min/\max} = \sum_{m=1}^{Number^{ev}} SOC_{m,t}^{\min/\max} \quad \forall k, \forall t \quad (21)$$

$$P_{k,t}^{ch/dch \min/\max} = \sum_{m=1}^{Number^{ev}} P_{m,t}^{ch/dch \min/\max} \quad \forall k, \forall t \quad (22)$$

C. Solving method

The techno-economic model is a mixed-integer nonlinear programming (MINLP) problem, which can be challenging to solve due to the presence of both nonlinear equations and binary variables. Relaxing the integer decision variable in the model transforms the MINLP into a nonlinear programming (NLP) problem, which can be easier to solve. By using the solution from the relaxed model as an initial point, the original MINLP problem can be solved using optimization algorithms, such as branch-and-bound or branch-and-cut. The scaling of the gas and electricity operation subproblems can also help to overcome the difficulties in solving the MINLP problem [18]. The main steps of the discussed solving method are demonstrated in detail in Table I.

TABLE I. PSEUDOCODE OF DISCUSSED SOLVING METHOD

Line	Algorithm
1	Iteration := 1;
2	Relaxing binary variables in the model;
3	Solving the relaxed model which is NLP;
4	If an optimal solution found;
5	Stop;
6	Else adding load shedding to electricity and natural gas flow and
7	corresponding penalty into the objective function, going to line 1, and
8	Iteration := Iteration + 1;
9	End
10	Setting output of the previous problem as initial points;
11	Solving the original problem which is MINLP;
12	If an optimal solution found;
13	Stop;
14	Else scaling natural gas and electricity operating problem, going to line 1, and
15	Iteration := Iteration + 1;
16	End

III. CASE STUDY

Illustrations of electricity and natural gas systems are represented in Fig. 2 and Fig. 3, respectively [16]. The electricity system is formed of 33 buses, 32 lines, four distributed renewable resources at buses 15, 29, 30, and 32, and two distributed dispatchable gas-fired units at buses 2 and 9, and three electric vehicles parking lots. The natural gas system is also formed of 11 nodes and 12 pipelines. The electricity system is connected to the main grid through a substation. The gas-fired dispatchable units also connect the electricity system to the natural gas system. More precisely, the gas-fired units at bus two and bus nine in the electricity system are connected to node five and node six in the natural gas system, respectively, to be supplied.

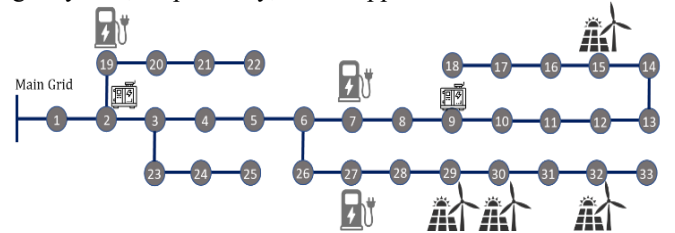


Fig. 2. Demonstration of electricity system in microgrid

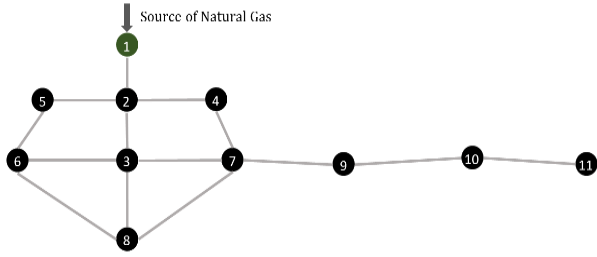


Fig. 3. Demonstration of natural gas system in microgrid

The shares of electric load (hourly to peak), natural gas loads (hourly to peak) as well as the output power of distributed wind turbines (available power/installed capacity) are demonstrated in Table II.

As discussed, the Gaussian Distribution Function is utilized to generate the scenario for arrival time, departure time, and state of charge of electric vehicles at parking lots. The scenario generation is conducted by considering the represented data in Table III.

TABLE II. SHARE OF ELECTRIC AND NATURAL GAS LOADS AND WIND POWER

Time (hour)	Electricity (%)	Gas (%)	Wind (%)	Time (hour)	Electricity (%)	Gas (%)	Wind (%)
1	0.6843	0.77	0.8345	13	0.9460	0.94	0.7601
2	0.6451	0.74	0.5361	14	0.9515	0.94	0.5987
3	0.6198	0.7	0.4424	15	0.9721	0.92	0.4704
4	0.6044	0.71	0.4220	16	0.9991	0.94	0.5162
5	0.6057	0.72	0.9124	17	1.0000	1	0.5641
6	0.6268	0.74	0.8579	19	0.9638	0.99	0.6466
7	0.6773	0.85	0.8981	19	0.9608	0.99	0.8375
8	0.7437	0.86	0.6792	20	0.9271	0.96	0.9480
9	0.8029	0.94	0.9266	21	0.9269	0.91	0.8187
10	0.8484	0.96	0.9083	22	0.8872	0.82	0.9185
11	0.8930	0.96	0.8075	23	0.7853	0.72	0.9699
12	0.9222	0.94	1.0000	24	0.7685	0.74	0.9002

TABLE III. PARAMETERS OF PARKING LOTS [17]

Parameter	μ	σ	Min	Max
Initial state of charge (%)	50	25	30	90
Arrival time (hour)	8	3	5	17
Departure time (hour)	16	3	11	24

According to the above-mentioned case study, this paper is modeled under the environment of General Algebraic modeling system (GAMS) software using the Discrete and Continuous Optimizer (DICOPT) solver. The operating system is Windows 10 64bit, and the hardware environment of the simulation test is Intel Core I7 CPU, 2.20 GHz, 8 GB memory.

IV. RESULTS AND ANALYSES

A. Scenario generation

Based on the model formulation, to conduct the techno-economic analysis of electric vehicles parking lot, a scenario for arrival time, departure time, and arrival state of charge of electric vehicles are generated. The generated scenario for each parking lot in the case study is indicated in Fig. 4. It should be noted that the cumulative arrival state of charge of electric vehicles in each parking lots are indicated. According to the generated scenarios, electric vehicles are in parking lots almost between 04:00 and 18:00.

B. Economic analysis

Considering the generated scenario that represents the state of charge of electric vehicle parking lots, the problem of techno-economic analysis is optimized. In this step, five cases are taken into consideration. In the first case, it is assumed

that the parking lots can use arrived electric vehicles to improve the electricity system operation. More precisely, there is no limit to utilizing the stored energy in electric vehicles' batteries. In the second and third cases, there are two and one electric vehicle parking lot(s) in the microgrid, respectively. In the fourth case, the electric vehicles' state of charge must be more than 90% when they are going to leave the parking lots. In the fifth case study, there are no electric vehicle parking lots. The operation cost of the electricity system and emission cost in each case is indicated in Fig. 5. It is evident that, in the first case, the scheduled charging and discharging of electric vehicles in parking lots reduces the cost of operation by 15% (i.e., the first case in comparison with the fourth case). Moreover, the scheduled operation of electric vehicles reduces the emission by 33% due to less operation of fossil fuel-fired generating units (the first case in comparison with the fourth case). Moreover, it is worthwhile to mention that the total investment cost for each parking, allocated to a one-day operating period, is 385\$. Therefore, the flexibility provided by electric vehicles in parking lots can compensate for a considerable portion of the investment costs.

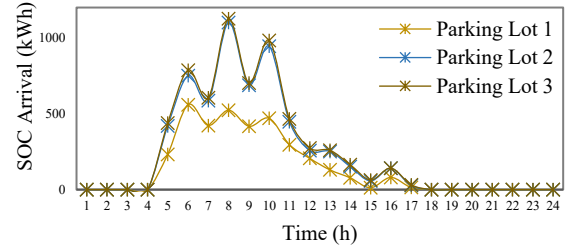


Fig. 4. Generated scenario for state of charge of each electric vehicle parking lot

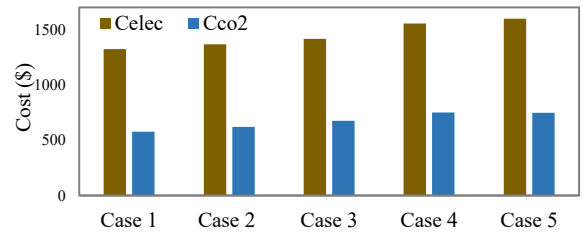


Fig. 5. Cost of electricity system operation and emission cost considering different cases

C. Technical analysis

To examine the reason for cost and emission reduction when the scheduled electric vehicles operation is considered, the output power of flexible dispatchable units (FG), distributed wind turbines (DG), interactions with the main grid (Deal), and charge/discharge of electric vehicles (Eveh/Evdch) in the first case and the fourth case are indicated to be compared in Fig. 6. As demonstrated, the output power of wind turbines is utilized to supply demand during the whole operation period. In the first case, the electric power is purchased from the main grid during the period from 00:00 to 10:00 and from 14:00 to 24:00. However, in the fourth case, it is purchased from 00:00 to 04:00 and from 14:00 to 24:00. In these two cases, the main difference is charging electric vehicles in parking lots. More precisely, in the fourth case, unscheduled charging of electric vehicles increases the peak load that leads to an increase in costs of operation and emissions.

Figure 7 shows the injection of natural gas through the main grid and the amount of linepack within pipelines in the gas system. The maximum natural gas injection in the fourth case is higher compared to the first case (from 17:00 to 22:00). It is concluded that the natural gas system is able to supply a higher amount of load during peak hours of operation since it is a scheduled integration of electric vehicles (from 06:00 to 09:00 and from 17:00 to 22:00). On the other hand, in the first case, the volume of linepack within the pipelines is more in comparison with the fourth case. As a result, this system can deliver natural gas to the demand node more efficiently (e.g., demand for gas-fired units). Gas transmission from the main grid to demand nodes takes some time, and a higher volume of linepack allows it to provide supply-demand balance in the gas system more effectively. In conclusion, in the first case, the natural gas system is more flexible in dealing with changes between supply and demand and addressing demand provision.

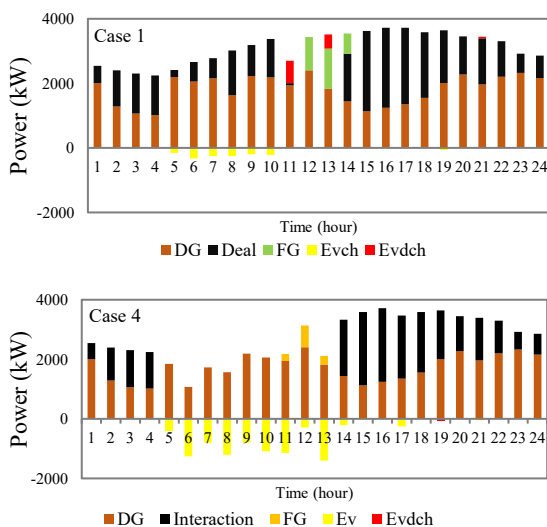


Fig. 6. Scheduling of electric system in microgrid (Case 1 vs. Case 4)

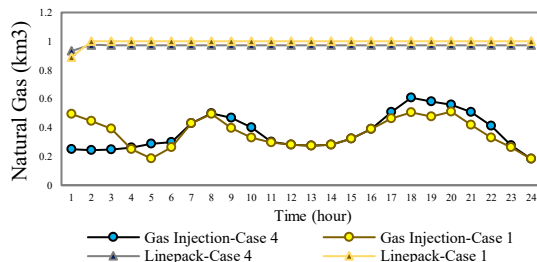


Fig. 7. Gas injection through main grid and linepack within pipelines in natural gas system

V. CONCLUSION

This study presented a model to analyze the role of electric vehicles parking lots in microgrids from technical and economic points of view. To this aim, a mathematical model was proposed for natural gas and electricity systems in a microgrid. The objective function of the model included the costs of investment, operation, maintenance, and emission. To model the electric vehicles in parking lots, a scenario was generated for arrival and departure time as well as the arrival state of charge of electric vehicles at each parking using the Gaussian Distribution Function. The results of the study

provided insights with microgrid owners, such as the impact of the scheduled and unscheduled operation of electric vehicles in parking lots, the required cost of investment, and the flexibility provided by the scheduled integration of electric vehicles. It showed that scheduled operation of electric vehicle parking lots could reduce the costs of operation and emission by 15% and 33%, respectively, compared to when there is no parking lot. Due to its inherent flexibility provided by electric vehicle parking lots, the natural gas system can efficiently adapt to changes in demand for natural gas, which is further supported by the higher stored natural gas within pipelines.

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