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Significant Characteristics of Multi Carrier Energy Networks for Integration of Plug-In Electric Vehicles to Electric Distribution Network

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Abstract

One of the big concerns of big cities is facing with the increase of fossil fuel vehicles in the roads. The cars intensify greenhouse gas emission in civic centers. One approach to reduce the emission is replacing the cars by Plug-In Electric Vehicles (PEVs). In spite of reducing the emission, PEVs have some adverse effect on electric distribution networks. Technical challenges such as load and loss factors are some of the considerable problems. In this paper, in order to overcome the problems, the effect of integration of different energy networks is introduced. Two scenarios are proposed. In first scenario, a parking lot is just supplied by just electric distribution network. In second scenario, the parking lot is supplied by electricity and gas networks. Finally, the significant effect of multi carrier energy networks to supply the vehicles is confirmed.

Keywords: Electric Vehicle; Multi Carrier Energy Networks; Loss and Load Factors.

1. Introduction

Growing energy demands and greenhouse gas emission are some of the most important problems of recent century. Permanently, energy distribution network companies are looking forward some solutions to subjugate the problems. PEVs have been increasing and are replacing instead of internal combustion engines in the roads. US department of energy has announced that 60% of US vehicles should be replaced by PEVs by 2020 [1]. In doing so, electric distribution network undoubtedly will deal with some technical and economic challenges in future years. Increase of load and loss in electric distribution network are some of the most important problems. One approach discussed recently is utilization of different energy networks dependently. In the past, energy distribution networks such as gas, heat, and electricity were operated dependently. Nowadays, some approaches and technologies simplifies integration of the networks. Combined Heat and Power (CHP) is one of the technologies that enables integration of different energy networks. Loss reduction, decrease of operation costs, and increase of reliability are some characteristics of the technology.

When PEVs are integrated to electric energy networks, they increase power loss and load as well as operation costs. In this paper, integration of gas and electric network is taken into account as a solution to reduce the aforementioned problems in the electric distribution network.

The idea for integration of electricity and gas networks has been considered in some recent works. One approach to utilization of different energy networks are “Micro Grid” [2]. “Hybrid Energy Hub” as another idea is discussed in [3]. Energy Hub

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Approach is debated in Vision of Future Energy Networks project [4].

Energy Hub is defined as a super node in electric power system. It receives electricity and gas from the networks to supply electricity and heat demands. Different technologies are used to convert input

Fig.1. A parking lot supplying electric vehicle

This paper is organized to consider important effect of CHP and combination of gas and electric networks to reduce the increase of operation costs, loss factor and load factor when EVs in parking lots are connected to the electric network. Consequently, two scenarios are introduced. In scenario 1, parking lot is just supplied by electric distribution network. In scenario 2, the parking lot is equipped by CHP and integration of gas and electric network to supply EVs in the parking.

2. Proposed Parking Lot

In order to compare between effect of loss and load factors as well as operation costs, two scenarios are presented. In scenario 1, parking lot is supplied by just electric distribution network. In scenario 2, the parking is supplied by both gas and electricity networks. Fig.1. shows a parking lot supplying electric vehicles.

3. Problem Formulation

In this session, two types of formulation are introduced. For scenario 2, supplying the parking lot with gas and electric distribution network is formulated in section A. Problem for scenario 1, supplying PEVs in the parking lot by just electric distribution network, is debated in section B.

3.1. Section A.

In this scenario, problem is formulated by an objective function (1) and its constraints (2) through (10). Load factor and loss factors can be calculated by (11) and (12).

3.1.1. Objective Function:

Objective function *OF* includes purchased electricity (*Elec*) from network with its price Pr^{Elec} and purchased gas from network (*Gas*) with its price Pr^{Gas}. Charge E^{ch} and discharge E^{dis} of PEVs in parking lot are controlled by hourly electricity price. *h* and *ev* denotes hour and type of PEV.

$$OF = \sum_{h=1}^{24} (\Pr^{Elec}(h)(Elec(h)) + \Pr^{Gas}(h)(Gas(h))) + \sum_{h=1}^{24} \sum_{ev=1}^{EV} \Pr ice(h)(E^{ch}(h,ev) - E^{dis}(h,ev)) \quad (1)$$

3.1.2. Constraints:

Electrical load *Load(h)* in parking lot and charge requirements of the parking should be equal by purchased electricity from network and converted gas to electricity by CHP (2). Gas to electricity efficiency of CHP is denoted by η^{CHP}. η^{Tr} denotes transformer efficiency. Purchased electricity and gas network should be less than maximum power of the networks in (3) and (4) in sequence. Produced electricity by converting gas to electricity by CHP should be limited by maximum capacity of CHP in (5).

$$Load(h) = \eta^{Tr} Elec(h) + \eta^{CHP} Gas(h) + \sum_{ev=1}^{EV} E^{dis}(h,ev) - \sum_{ev=1}^{EV} E^{ch}(h,ev) \quad (2)$$

$$Elec(h) \le Elec^{Max} \quad (3)$$

$$Gas(h) \le Gas^{Max} \quad (4)$$

$$\eta^{CHP} Gas(h) \le CHP^{Max} \quad (5)$$

Each battery of PEV is restricted by available energy, charge and discharge energy of it in (6) [6]. Battery energy should be limited by its maximum capacity E^{Max} (7). Charge and discharge energy are limited in (8) and (9) in sequence. α^{ch} and α^{dis} show charge and discharge efficiency of the battery. Binary variable of charge and discharge are used to prevent charge and discharge simultaneously (10).

$$E(h,ev) = E(h-1,ev) + E^{ch}(h,ev) - E^{dis}(h,ev) \quad (6)$$

$$0 \le E(h,ev) \le E^{Max} \quad (7)$$

$$0 \le E^{ch}(h,ev) \le (1/\alpha^{ch}) E^{Max} I^{ch}(h,ev) \quad (8)$$

$$0 \le E^{dis}(h,ev) \le \alpha^{dis} E^{Max} I^{dis}(h,ev) \qquad (9)$$

$$0 \le I^{ch}(h,ev) + I^{dis}(h,ev) \le 1 \qquad (10)$$

Load factor is defined average of electrical load (in duration of time) to maximum load (in that duration of time) (11). Loss factor is defined average of loss power to maximum loss in duration of time (12) [8]. Here, the load factor as well as loss factor is taken into account for the effect of the renewable and energy storages on the technical factors. P^{Max} denotes maximum value of the load in the duration.

$$LF = \frac{\left(\sum_{h=1}^{24} Elec(h)\right)/24}{Elec^{Max}} \qquad (11)$$

$$LOF = 0.7LF^2 + 0.3LF \qquad (12)$$

3.2. Section B.

In this scenario, problem is formulated by the objective function (1) without purchased gas from the network and its price. Constraint of (2) is applied without CHP. Constraint (3) and constraints (6) through (10) should be also applied. Load factor and loss factors can be calculated by (11) and (12).

4. Simulation Results

Simulation is applied on a parking lot including PEVs. Two different scenarios are introduced. In scenario 1, the parking lot lacks a CHP for combining different energy networks. Parking lot is directly supplied from electric network, and redundant electricity existing in PEVs can be sold to electric distribution network. In scenario 2, the parking lot contains CHP. This technology enables the integration of different energy networks together. In this case, electricity and gas networks are integrated in order to supply energy of PEVs in parking lots.

In this paper, three different PEVs with three different battery capacities in parking lot are considered. 16 kW, 30 kW, and 48 kW are three different batteries in parking lots. Charging and discharging efficiency of batteries are assumed 0.9. Loss coefficient of batteries is supposed 0.05. Maximum capacity of electric distribution network is 3000 kW. Capacitance of gas pipeline is assumed that 1000 kW. Transformer efficiency is 0.9. Gas to electric efficiency of CHP is 0.4. Amount of CHP capacity is 700 kW. Hourly electricity price is shown in Table I. Available PEVs in the parking lot in three different hours a day are given in Table II. Hourly electric load is presented in Fig.2.

Table.2
Available vehicles in parking lot in different hours

Time	PEVs Numbers in the Parking	Time	PEVs Numbers in the Parking
H1	0	*H13*	300
H2	0	*H14*	250
H3	0	*H15*	200
H4	0	*H16*	200
H5	0	*H17*	150
H6	20	*H18*	150
H7	60	*H19*	120
H8	100	*H20*	100
H9	150	*H21*	50
H10	200	*H22*	25
H11	250	*H23*	20
H12	300	*H24*	10

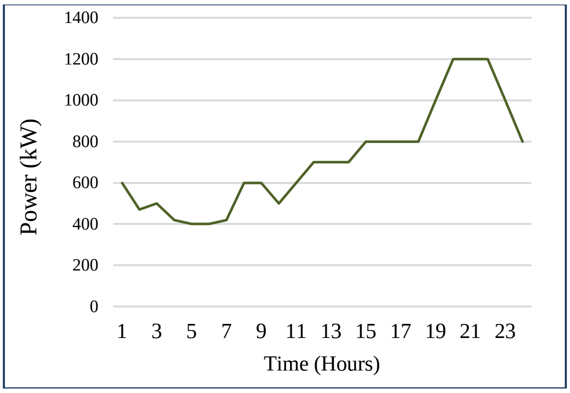

Fig.2. Hourly electric load

Based on the parameters and scalars were discussed in the last paragraph, the simulation is applied on the parking lot in two different aforementioned scenarios. Simulation results are demonstrated in Fig. 3, Fig. 4, Fig.5, and Fig. 6. Table 3 shows the amount of power that is purchased from electricity and gas networks in two different scenarios.

It can be observed from Fig. 3, when the parking lot is independently supplied by electric distribution network and gas energy network is not employed in this scenario or scenario 1, parking lot's requirement to be supplied by electric distribution network is inevitable. Therefore, the parking lot or proposed hub should purchase more electricity from the network compared to the scenario that the parking lot has voluntary option to be supplied by electric or gas networks. Thus, as it can be observed from Fig. 4, operation costs is reduced when the parking lot is supplied by both electricity and gas networks.

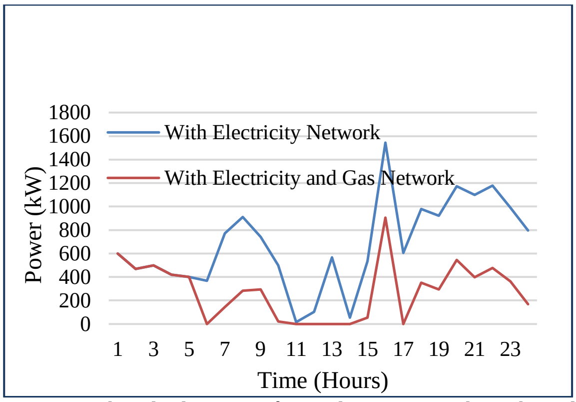

Fig.3. Purchased electricity from electric network with and without integration of different energy networks in the parking lot

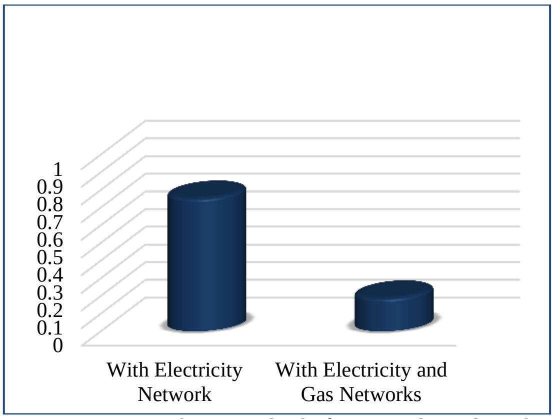

Fig.5. Comparison between load factor with and without integration of different energy networks in the parking lot

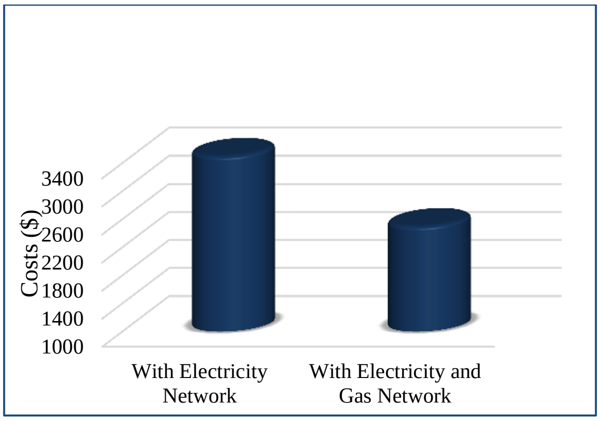

Fig.4. Comparison of operation of energy costs with and without integration of different energy networks in the parking lot

Table.3.
Results of utilization of energy carriers with and without considering multi carrier energy network for supplying PEVs in parking lots

Time	Purchased Electricity from Network Without Gas Network	Purchased Electricity from Network With Gas Network	Purchased Gas from Network With Gas Network
H1	600	600	875
H2	470	470	875
H3	500	500	875
H4	420	420	875
H5	400	400	875
H6	367.5	0	1388.9
H7	771.6	143.1	1571.4
H8	910.9	282.3	1571.4
H9	743.9	293.9	1200
H10	500	20	1200
H11	15.3	0	875
H12	102	0	996.4
H13	567.8	0	1659.7
H14	53.8	0	832.2
H15	534.9	54.9	1200
H16	1543.5	905.9	1200
H17	604.5	0	1571.4
H18	979.1	350.6	1571.4
H19	922.5	293.9	1571.4
H20	1173.4	544.9	1571.4
H21	1099.9	399.9	1759.3
H22	1178.6	478.6	1759.3
H23	991.2	362.6	1571.4
H24	797.7	169.1	1571.4

It can be observed from Fig. 3, when the parking lot is independently supplied by electric distribution network and gas energy network is not employed in this scenario or scenario 1, parking lot's requirement to be supplied by electric distribution network is inevitable. Therefore, the parking lot or proposed hub should purchase more electricity from the network compared to the scenario that the parking lot has voluntary option to be supplied by electric or gas networks. Thus, as it can be observed from Fig. 4, operation costs is sensibly reduced when the parking lot is supplied by both electricity and gas networks.

It can be seen that utilization of gas and electric networks decreases the operation costs by 30% compared to the scenario 1 that energy networks are independently operated. Furthermore, reduction of load and loss factors is respectively seen in Fig. 5 and Fig. 6 when electricity and gas networks are dependently utilized by the parking lot. 74% load reduction is as the result of integration and operation of gas and electricity networks in the parking lot. 60% decrease of loss factor in the parking lot results from integration of multi carrier energy networks in the parking.

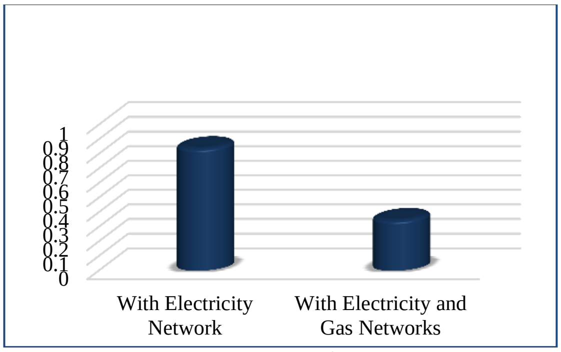

Fig.6. Comparison between loss factor with and without integration of different energy networks in the parking lot

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5. Conclusion

One of the remarkable solution to solve problem of growing greenhouse gas emission in big cities is substituting Internal Combustion Engine (ICE) by Plug-in Electric Vehicles (PEVs). Moreover, supplying Plug-In Electric Vehicles should be concerned by PEV owners and companies. In this paper, important effect of multi carrier energy networks while integration of parking lots to electric distribution network was taken into account. Two scenarios were introduced. In scenario 1, electric network is just used by parking lot owner to produce energy requirements of PEVs. In scenario 2, the parking lot uses gas and electricity networks to supply PEVs in parking lots. Comparison between different scenarios demonstrates the important effect of dependent utilization of different energy networks when PEVs in parking lots are integrated to electric network. As it can be demonstrated from the results, remarkable results of operation costs, load and loss factors reduction are as utilization of different energy networks in parking lots. For instance, the results of this paper confirm that 30% operation costs reduction, 74% load and 60% loss factors are as the result of dependent operation of gas and electricity networks in parking lots compared to utilization of just electric network.

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