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Infrastructure planning for airport microgrid integrated with electric aircraft and parking lot electric vehicles

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ABSTRACT

To achieve net-zero emissions in aviation industry with defined CO_2 mitigation objectives in "Flightpath 2050″, electric propulsion system becomes an attractive technology. Many electric aircraft (EA) prototypes with a fully electrically powered propulsion system for short-haul commuting air transport have been designed in recent years. Planning and designing the ground power systems and associated electric aircraft charging facilities are also essential for realising aviation electrification. In this work, a bi-objective infrastructure planning framework for airport microgrid to accommodate parking lot electric vehicles (EVs) and EA is developed, and the impact of V2G on the airport microgrid is assessed. The dispatching problem of the airport microgrid is formulated as a heuristic optimisation problem, and the NSGA-II algorithm is adopted to find the Pareto Fronts and optimal solutions. There are two different scheduling strategies for charging EA: plug-in charge and battery swap. The economic and technological assessments for both strategies are conducted and compared. The results show that adopting V2G strategy can improve the airport microgrid economic performance. In general, the EA plug-in charge strategy performs better than the EA battery strategy in terms of microgrid resilience, while the EA battery swap strategy can reduce the operation costs of the airport microgrid.

1. Introduction

With the growing interests in aviation electrification, electric aircraft (EA) has the potential to significantly reduce the environmental impacts of the aviation sector. By eliminating various air contaminants and potentially addressing global warming concerns, EA can offer considerable benefits, including the reduced carbon emissions and noise levels due to electric propulsion systems, particularly during take-off and landing [1]. In recent years, many companies have been working intensively to bring the concept of all-electric flight to practice, focusing on overcoming challenges such as increasing battery energy capacity and developing innovative electric propulsion systems [2]. It is becoming increasingly evident that electric propulsion systems are the future of aviation, with further electrification of aircraft anticipated [3,4].

In this context, previous studies have focused on designing efficient charging systems as a crucial aspect of integrating EA into commercial airports. In Ref. [5], the authors presented a multi-agent real-time microgrid energy scheduling solution for electrified air transport to address the stochastic EA charging needs. Ref. [6] introduced a novel Aviation-to-Grid (A2G) concept that utilises EA charging to provide flexibility to the power grid. In Ref. [7], the authors explored optimal airport charging infrastructure for EA and compared battery swap and plug-in charging systems in terms of flexibility, costs, and revenue at different EA penetration levels. Ref. [8] proposed an optimisation model for designing charging networks for EA between airports, which is solved using a Kernel Search heuristic algorithm. Ref. [9] examined the impact of EA battery charging on airport operations and infrastructure by employing queuing theory and simulation modelling techniques. Ref. [10] presented a novel ground support scheduling problem for EA, indicating that aviation electrification may lead to flight delays, especially in smaller airports. In Ref. [11], the authors proposed two strategies—power-optimised and power-investment-optimised—for EA battery swaps and recharging. The results demonstrated that the proposed strategies can substantially reduce peak power requirements and electricity costs. While few studies focus on planning EA charging systems, the charging system design for heavy-duty electric trucks could provide an alternative reference for integrating EA into airports. The smart charging system for heavy electric vehicles (EVs) presented in Ref. [12] achieved a 46% reduction in monthly costs compared to

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uncontrolled charge scenarios. In Ref. [13], the battery swap strategy for charging heavy electric trucks was found to be a more economical solution for medium recharge distances. It can be found that there are two strategies to accommodate EA in the airports, which are plug-in charge and battery swap. However, current research has not focused on the interactions between EA charging systems and airport energy systems. Additionally, comprehensive evaluations of different charging strategies (plug-in charge and battery swap) for EA have not been conducted.

Many research efforts have focused on the integration of EVs into energy systems in recent years [14,15]. Most of these studies investigated the impact of Vehicle-to-Grid (V2G) technology provided by EVs on energy systems [16]. Ref. [17] proposed an intelligent energy management system that optimises emissions, energy costs, and battery state of charge (SOC) using the NSGA-II algorithm. Ref. [18] provided a techno-economic evaluation of wireless charging, wired charging, and conventional technologies as potential options for electrifying airport shuttle buses. In Ref. [19], the authors presented a model predictive control approach for integrating EVs and hydrogen fuel cell stations, which improved transmission loss and enhanced the comfort of EV users. These studies suggested that V2G technology can offer various benefits to the operation of energy systems.

Based on the literature analysis, there is a knowledge gap in comprehensively evaluating the feasibility of planning airport microgrids that accommodate EA and parking lot EVs. To fill this research gap, this article proposes a bi-objective airport microgrid planning framework for electrified air transport accommodating parking lot EVs and EA in which the optimal dispatch of airport microgrid operation along with EA charging scheduling and V2G from parking lot EVs is proposed. Besides, a comprehensive annual analysis with meteorological profiles for an entire year is also conducted. The novel contributions of this work can be outlined as follows:

(1) A novel approach for coordinated scheduling of EA and airport parking lot EV charging demand is proposed. The proposed approach coordinatively dispatches EVs and EA charging demand according to flight schedules and airport operation conditions.
(2) This study formulates and compares two different scheduling strategies (plug-in and battery swap) for adopting EA battery charging and further quantifies the benefits of applying these strategies from economic and airport microgrid operational perspectives.
(3) This study develops a bi-objective optimisation framework that is applicable to managing the airport microgrid integrated with parking lot EVs and EA and improving its flexibility by coordinately scheduling EV and EA charging demand. Moreover, the impact of V2G on the airport microgrid is also assessed.

2. Airport microgrid architecture with EV and EA

The adoption of charging infrastructure for airport parking lot EVs and EA will significantly increase energy consumption, necessitating high penetration of distributed energy resources (DERs). An airport microgrid system is proposed to manage the electric load of the airport building, EA and EV charging demand, hydrogen system, photovoltaic (PV) and wind turbine (WT), as shown in Fig. 1.

Currently, gas turbines are widely adopted as DERs in airport energy supply systems. However, more and more airport operators have set up goals for carbon neutrality and emission reduction. The Flightpath 2050 plan, made by the European Union, has set a highly ambitious goal of decarbonising aviation by 2050 [20]. It envisions hydrogen fuel as a key technology to eliminate CO_2 emissions from the aviation sector. Additionally, the UK Department for Transport has also set a goal to decarbonise all forms of transportation in the UK by 2050 [21]. To decarbonise the airport energy supply systems and reduce the ground CO_2 emissions, the hydrogen system will become a more promising DER in the future [22]. In this work, we assume that there will be hydrogen fuel cells with an external hydrogen supply replacing gas turbines to serve as on-site generators in the airport microgrid. In this context, the airport operator will purchase hydrogen from the external supplier according to daily day-ahead energy dispatch results. The hydrogen system utilised consists of the hydrogen storage tank and fuel cell. The outline of the proposed bi-objective infrastructure planning framework for airport microgrid is illustrated in Fig. 1, in which both the EA and EV charging scheduling strategies are considered. The airport microgrid infrastructure planning framework not only fulfils the airport electric demand and EA charging demand but also benefits from the flexible scheduling of EVs and EA.

2.1. Two EA charging scheduling approaches

The Eviation Alice is selected as a reference EA, which is designed for domestic commuting flights with a travel distance range suitable for such purposes. Expected to be adopted in commercial airports by 2027, it will replace conventional commuter aircraft such as the Saab 340B (SF3), which typically transport 20–50 passengers and cover distances of less than 500 nautical miles. With a passenger capacity of 9 (+2 crew), a distance range of 440 nm, a battery energy of 900 kWh, and a rated charging power of 0.63 MW, the Eviation Alice has a smaller capacity compared to the 36-passenger SF3. As a result, it is estimated that four

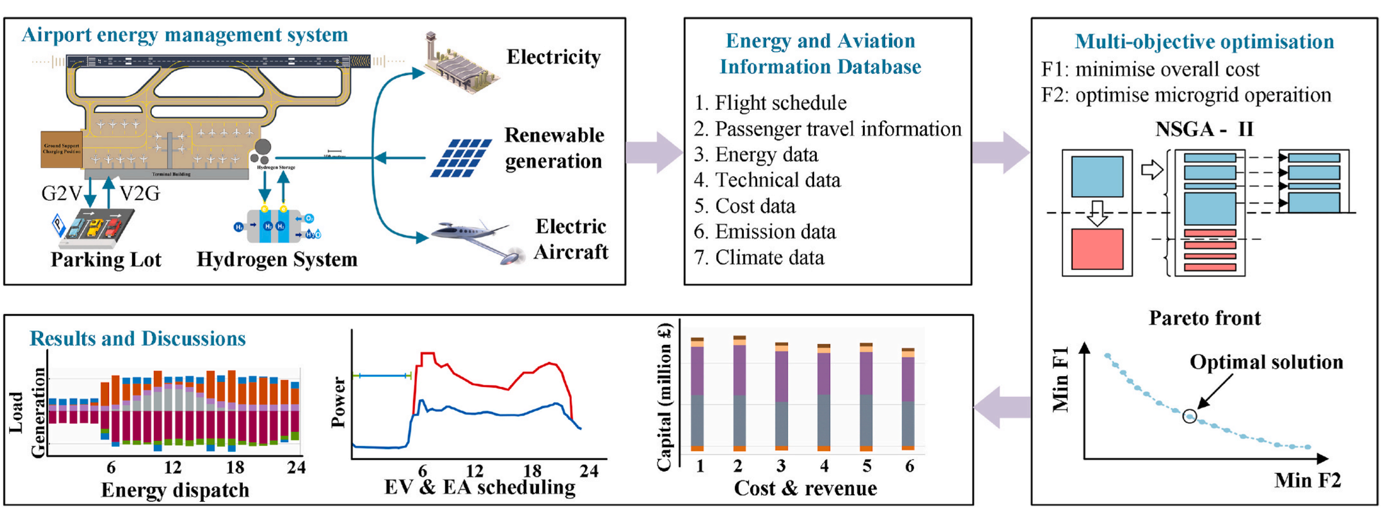

Fig. 1. The outline of the proposed optimisation framework for airport microgrid.

EAs will be required to carry out one existing commuter flight mission. In order to prevent simultaneous high-power charging on airport microgrids, flights will be rescheduled, with one flight mission conducted by conventional aircraft being evenly distributed into four missions conducted by EA, as shown in Fig. 2.

Two EA charging approaches exist in this field, similar to current EVs: plug-in charge and battery swap. The plug-in charging occurs during turnaround time when the aircraft is parked at the apron, while the battery swap approach involves swapping batteries upon parking, with recharging happening during off-peak electricity times, necessitating additional batteries. To determine the optimal charging solution, airport terminal building demand patterns are analysed, revealing general energy consumption features for medium-sized airports [23], as shown in Fig. 2. The lowest demand time is between 0 and 6 o'clock when few flights and passengers are present, making it the preferred period for long-term parking EV and swapped EA battery charging. For plug-in charging, to increase flexibility, EAs are rescheduled within a 2-h range from the original arrival time of conventional aircraft.

2.2. Airport parking lot EV scheduling

Unlike other commercial or residential districts, airports are hubs between ground transport and air transport. As a result, the airport parking lot EV management differs from most districts penetrated with EVs. Firstly, most airports have separate parking lots for short-term and long-term EV parking. In this work, passengers who book to-and-from tickets and drive to the airport are defined as long-term parking EV owners. Usually, the long-term parking passengers who choose to travel to and from the airport tend to book tickets in advance with a certain return date which can be linked to the flight schedules. This behaviour benefits the airport operators by facilitating the collection and prediction of parking lot demand data. Furthermore, long-term parking EVs could be effectively utilised as aggregated energy storage units. Similar to other commercial areas, there are also short-term parking EVs predominantly owned by the airport staff. At Luton Airport, 46% of the passengers decided to travel to the airport by their private cars. In order to reduce the congestion of airport parking lots, airport operators tend to limit the number of employers who travel to and from work by car to 60% [24].

The behaviours of passengers and employees are assumed to be subject to Gaussian distributions and have a dependent relationship with the flight schedules. A set of flights F with their arrival time, departure time, and number of passengers are defined to represent the flight schedule in (1). Based on the relationship between passenger travel patterns (arrival time, departure dates and hours) and flight schedules, the passenger profile can be derived as shown in (2). The detailed process is illustrated in Supplementary Note 2.

$$F = \left\{ T^{arr}_{f1}, T^{arr}_{f2}, \ldots T^{arr}_{fN}; T^{dep}_{f1}, T^{dep}_{f2}, \ldots T^{dep}_{fN}; N^{pass}_{f1}, N^{pass}_{f2}, \ldots N^{pass}_{fN} \right\} \tag{1}$$

$$E^{p} = \left\{ T^{arr}_{1}, T^{arr}_{2}, \ldots T^{arr}_{K}; T^{dep}_{1}, T^{dep}_{2}, \ldots T^{dep}_{K}; SOC^{EV}_{init,1}, SOC^{EV}_{init,2}, \ldots SOC^{EV}_{init,K} \right\} \tag{2}$$

The airport facilities are typically designed to meet the traffic demand during a design peak day (DPD) to ensure the airports are designed with adequate capacity to handle demand at extreme peaks [25]. There are various DPD selection methods. In this study, considering the monthly and seasonal impacts on the flight missions, the peak day of the peak month is selected as DPD. The peak day flight schedule of the busiest month (May) is selected in this analysis, as shown in Fig. 3.

2.3. Uncertainty representation

There are uncertainties in the input EV parking profiles. To address these uncertainties, a stochastic programming approach is employed. First, we generate various EV parking profiles using the profile generation method described in the previous section. Next, we apply the k-means clustering method to create N_s representative EV parking profiles for clustered scenarios. The probability of each scenario is determined by the proportion of represented profiles relative to the entire set of profiles, denoted by ρ_s. This approach enables us to account for uncertainties in EV parking profiles and develop more robust energy management strategies. The scenario-based method is utilised in the optimisation problem to solve the uncertainties due to stochastic EV scheduling profiles. The detailed uncertainty representation profiles can be found in Supplementary Note 2.

3. Optimisation framework for airport microgrid

In this section, the principles and overview of the mathematical formulations are introduced, the detailed deviation for the equations is demonstrated in Supplementary Note 3.

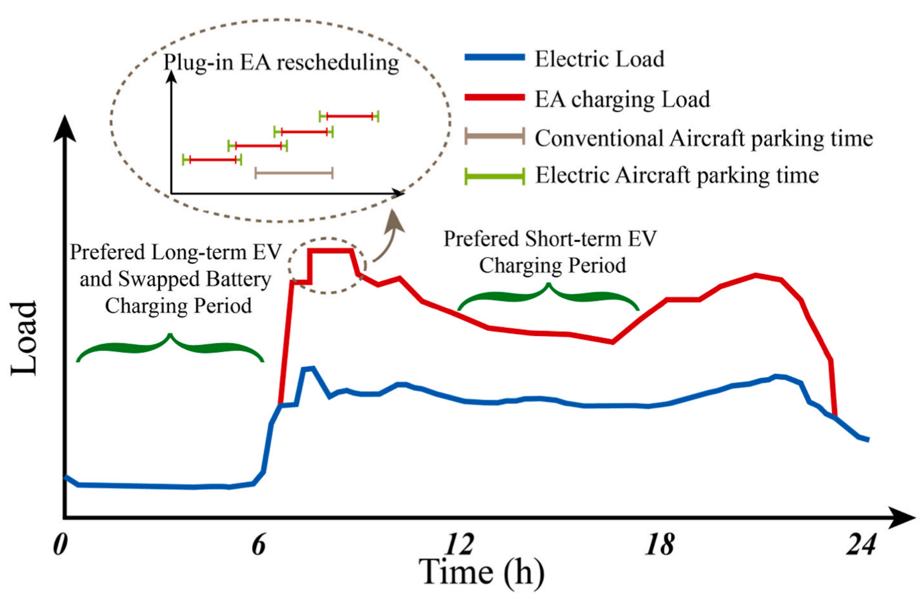

Fig. 2. Airport electric load and EA EV charging load.

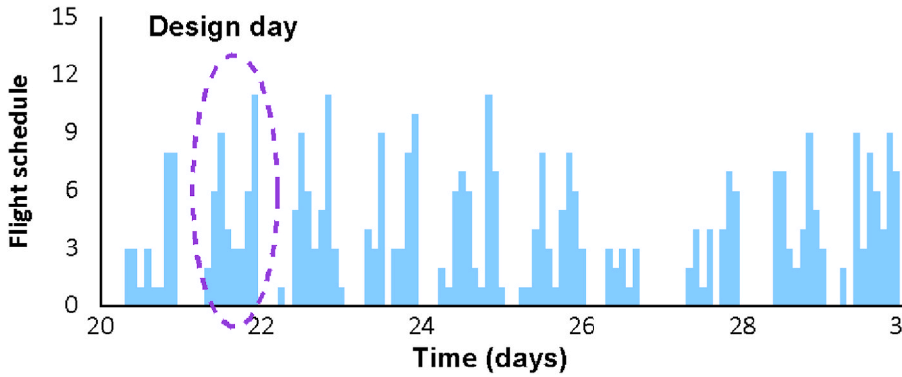

Fig. 3. Flight schedules and EV parking scheduling profiles of the East Midland Airport over one month.

3.1. Objective functions

The proposed optimisation framework for airport microgrid energy management system is formulated as a heuristic optimisation problem, two objectives have been considered: the annualised total cost of the system, and the resilience factor (*RF*) of microgrid, as shown in (3)–(6).

$$\min(f_1 = CAPEX + OPEX) \tag{3}$$

$$\min\left(f_2 = RF = \sum_{t=1}^{T} \frac{P_{t,s}^{im}}{P_{t,s}^{demand}}\right) \tag{4}$$

$$CAPEX = \frac{r\cdot(1+r)^y}{(1+r)^y - 1}\sum_{dev}\left(CAP_{dev}\cdot \pi_{dev}^{CAP}\right) \tag{5}$$

$$OPEX = \frac{1}{N_s}\sum_{s=1}^{N_s}\rho_s\cdot\left(C_{EP,s} + C_{CO_2,s} + C_{main,s} + C_{deg,s} + C_{pen,s}\right) \tag{6}$$

3.2. Energy balance constraints

The airport electric load, EV and EA charging demand are locally supported by PV, WT, hydrogen fuel cell and discharging power from V2G services. When distributed power generation is inadequate to sustain the system, the deficit is compensated by importing power from the upper grid, as shown in (7).

$$P_{t,s}^{im} + P_t^{PV} + P_t^{WT} + P_{t,s}^{FC} + P_{t,s}^{EVdisc} = P_t^{E} + P_{t,s}^{EVc} + P_{t,s}^{EA} \tag{7}$$

3.3. EA charging algorithms

As discussed in Section 2, there are two EA charging approaches proposed in this study. For the EA plug-in charge scenario, the EA battery charging power equals to the summation of the number of EA parking at apron after re-scheduling, as shown in Equation (8) and (9).

$$P_{fn,T_{fn}^{arr}+T_{fn}^{re},s}^{EA} = P^{EA,rated}, fn = f1, f2, ..., fN \tag{8}$$

$$P_{t,s}^{EA} = \sum_{fn} P_{fn,t,s}^{EA} \tag{9}$$

With respect to the EA battery swap scenario, EA charging demand is allocated between 1 and 6 a.m. to fill the valley of the airport energy demand, and in the rest of the operation time (after 6 a.m.), the number of fully charged batteries will be taken by EA flight demands. The flow of in-station EA batteries is described by (10).

$$n_{t,s}^{f} = \begin{cases} n_{t-1,s}^{f} + n_{t,s}^{full} & 2 \le t \le 6 \\ n_{t-1,s}^{f} - n_t^{d} & t > 6 \end{cases} \tag{10}$$

3.4. EV charging and discharging constraints

The heuristic algorithm is not capable of handling a high number of variables that represent the charging and discharging of every EV. As a result, the aggregate management strategy is utilised to reduce the dimension of decision variables. There are two types of control strategies for airport parking lot EVs: G2V (operating as electric loads) and V2G (operating as energy storage). For the G2V strategy, the EV charging loads are allocated at a specific period of the day before the leaving time of EV owner passengers. For the V2G strategy, the EVs are available for charging and discharging while staying at the airport parking lot.

4. Results and analysis

4.1. Overview

In this work, case studies are conducted at East Midland Airport (IATA code: EMA) using 2019 aviation demand data to avoid COVID-19 impact. Domestic flight schedules from August 1st to 30th 2019 are used to generate the EA flight schedules and EV parking profiles. It is assumed that 50% of domestic flights to-and-from EMA are electrified. A 25-kWh battery capacity EV is chosen for the simulation, with a 10-kW charging/discharging power rate and 92% efficiency. The maximum and minimum SOC for EVs are set at 90% and 20%, respectively. The EA charging efficiency is assumed to be 95%. The peak demand for airport terminal building load is 10 MW, with maximum installation capacities of 9 MW and 10 MW for WT and PVs, respectively. Other assumptions include an initial SOC of 0.2 for arrival EA and a 500 kg hydrogen storage tank requirement for each hydrogen fuel cell stack (1 MW). The electricity price varies by time of day, with 0.1 £/kWh during off-peak hours and 0.2 £/kWh during peak hours (7 a.m. to 9 p.m.). CO_2 emission costs and hydrogen prices are constant at 20 £/t and 5£/kg, respectively, and the electricity carbon factor is 0.257 kg/kWh. Other economic inputs including investment and maintenance costs for each energy device are shown in Table 1.

The costs and specifications related to EV batteries are as follows: The labour cost for replacing a battery is 240 £, and the battery life cycle is 5000 cycles, with a depth of discharge (DOD) of 80%. Six case studies

Table 1
Economic parameters of devices [26,27].

Device	Installation cost	Maintenance cost (per year)	Device	Installation cost
PV	2245 £/kW	28.7 £/kW	EV Chargers	1300 £/each
WT	1451 £/kW	37.5 £/kW	EV/EA battery	300 £/kWh
Fuel Cell	501.64 £/kWh	11.57 £/kW	Transformer	25,000 £/MVA
Hydrogen tank	1341 £/kg	15.65 £/kW	EA Chargers	10,000 £/each

are investigated to explore the effects of V2G and different EA scheduling approaches. The proposed bi-objective infrastructure planning framework and the NSGA-II algorithm are coded in MATLAB 2021a on a PC with Intel Core i7-11700 @ 2.5 GHz and 16 GB of RAM. The size of the populations and the number of iterations are set as 200 and 2000, respectively. The mutation probability and crossover rate of the NSGA-II algorithm are set at 0.5. To explore the effect of V2G and different EA scheduling approaches, the following six case studies are investigated: Case 1, EA plug-in charge without Parking Lot EVs; Case 2, EA plug-in charge with G2V; Case 3, EA plug-in charge with V2G; Case 4, EA battery swap without Parking Lot EVs; Case 5, EA battery swap with G2V; Case 6, EA battery swap with V2G.

4.2. Microgrid energy dispatch

To investigate the impacts of different EA charging scheduling strategies and G2V/V2G on the airport microgrid energy dispatch, the energy dispatch results of the airport microgrid in all 6 cases have been presented in Fig. 4. As shown in Fig. 4, the load characteristics of EA plug-in charge cases and battery swap cases are different, it is evident that the load curves of EA battery swap cases are more flattened than EA plug-in charge cases. By introducing battery swap technology to EA charging scheduling, a more balanced and smoother electric load pattern in airport microgrids could be achieved. Around half of the airport loads, including the charging of EVs and EA, are supplied by renewable power generation. But due to the limited installation capacity of the PV and WT generation, the microgrid has to request power from the main grid. When the EA charging load exceeds the microgrid generation limits, the hydrogen fuel cell system operates to support the system to achieve power balance by generating electricity from the hydrogen storage tank.

Meanwhile, the parking lot EVs can serve as an alternative stable distributed energy storage during the daytime. As shown in Fig. 4 (c) and (f), the hydrogen fuel cell system generation operates less with the existence of V2G for both EA plug-in charge and battery swap cases, which also proves the V2G from parking lot EVs and hydrogen fuel cell system work together to satisfy the total demand of the airport microgrid hence improve the resilience of the airport microgrid. Hydrogen fuel cell system also tends to generate electricity when renewable generation is not at its peak. The parking lot EVs tend to charge during renewable generation and the valley of other demands because this will improve the resilience factor and renewable self-consumption rate. Generally, the airport microgrid demand for the EA battery swap scenarios seems more flattened than the plug-in scenario no matter whether EVs are involved, which proves that the adoption of the EA battery swap strategy is more beneficial to airport peak load shaving and valley filling than V2G from airport parking lot EVs because of the gap of their capacity.

4.3. EA scheduling

This section discusses the EA charging scheduling results and the interactions between EV and EA. By observing Fig. 5, it shows clearly that the EA battery swap cases require more chargers than EA plug-in charge cases. As shown in Fig. 5 (a), the demands for EA charging in EA battery swap cases are flattened rather than unevenly fluctuated, which is the best solution to reduce the total number of chargers needed. In EA plug-in charge scenarios, the EA charging demands in both V2G and G2V cases show different characteristics: the EA charging demand in the V2G case is smoother than the G2V case. This is because the V2G process makes the energy price more balanced during the daytime. The peak of EA charging demand in the daytime for the G2V case appears at 4–6 p.m. when the renewable resources are generating electricity, proving that the charging schedule of the G2V case relies more on renewable generation. The result of the G2V case shows that the previous evening peak (6–8 p.m.) has been shifted to a later time for better energy price and efficiency. By contrast, there are still morning peaks (9–10 a.m.) and evening peaks (6–8 p.m.) in the V2G case. The results indicate that if the airport operators tend to maintain the daily flight schedule curves, V2G could bring more benefits in terms of the airport microgrid scheduling performance.

4.4. Economic assessment

This section discusses the economic assessment for the optimal solutions for the investigated 6 cases. As shown in Fig. 6, the cost of G2V cases (Case 2 and Case 5) are the highest among the scenarios (EA plug-in charge or battery swap) respectively. At the same time, Case 3 (EA plug-in charge case with V2G) has the lowest cost among all EA battery swap cases. The adoption of V2G reduces the CAPEX and OPEX in EA plug-in charge cases significantly: Case 3 reduced 12.9% OPEX compared to Case 2. Similarly, the reduction in OPEX is also significant in EA battery swap cases, which is 20.4%. The results indicate that the

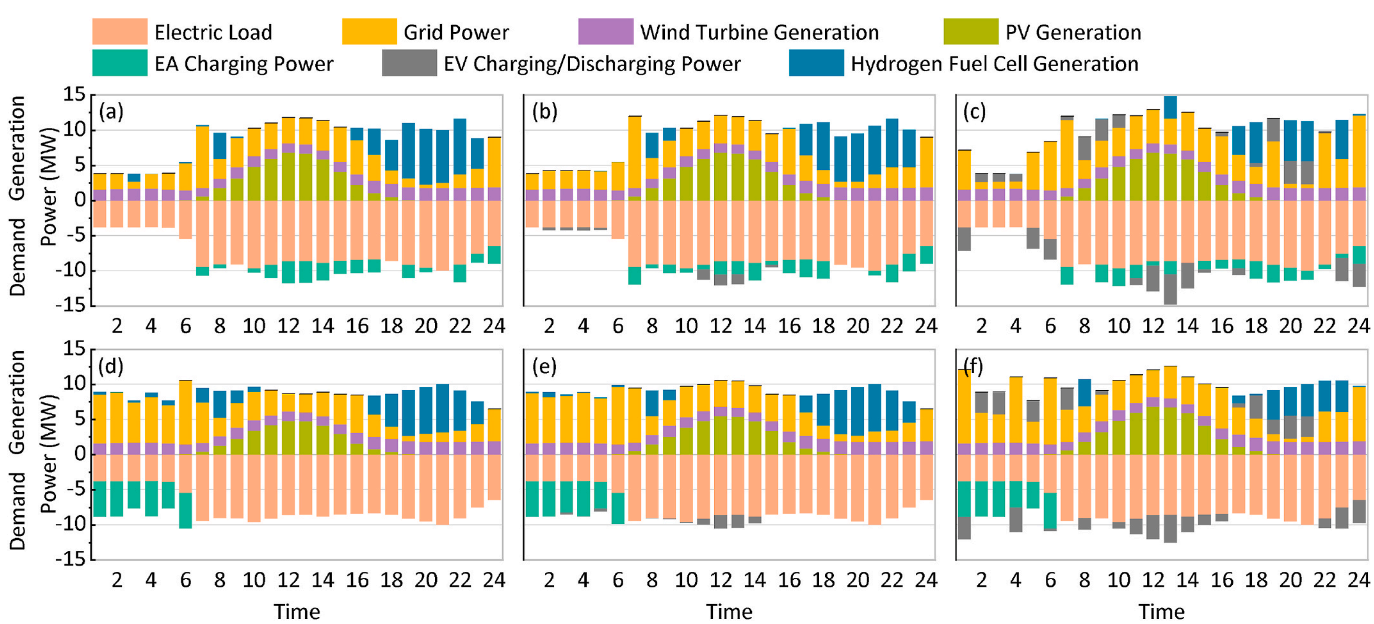

Fig. 4. Energy dispatch results for an example peak day of the airport microgrid (a) Case 1, (b) Case 2, (c) Case 3, (d) Case 4, (e) Case 5, and (f) Case 6.

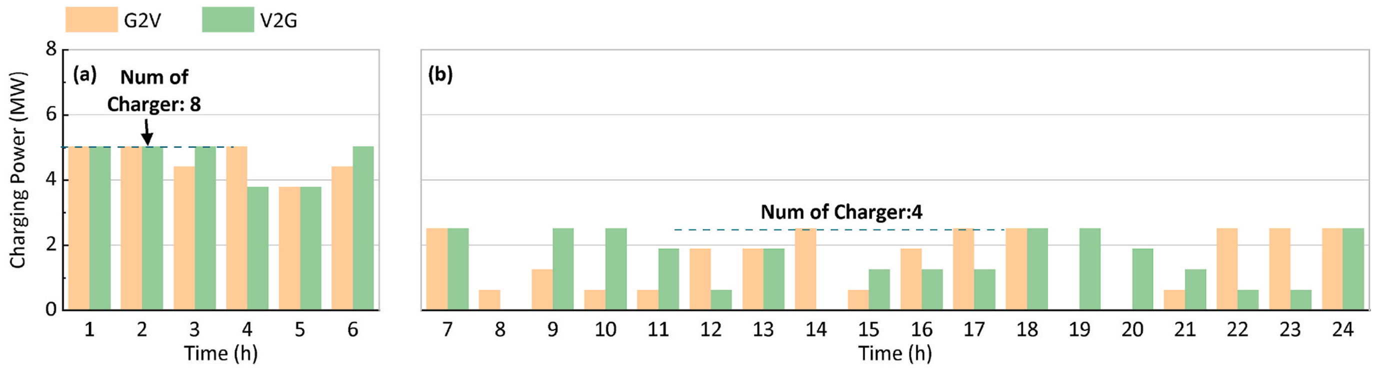

Fig. 5. The EA charging schedules for four cases (a) EA battery swap cases with G2V and with V2G, (b) EA plug-in charge cases with G2V and with V2G.

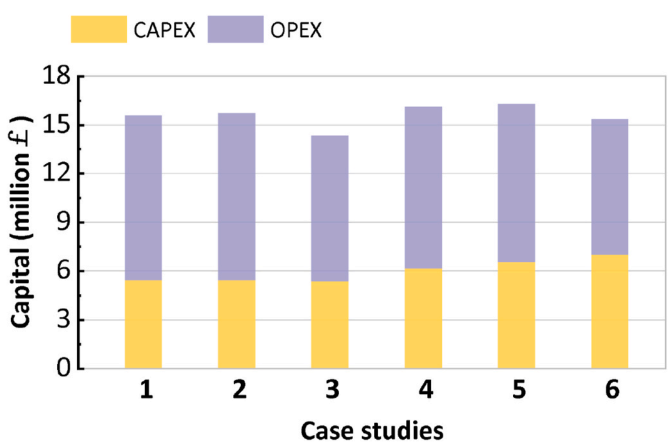

Fig. 6. Annualised Costs for the 6 cases.

V2G is beneficial to the airport microgrid in both economic and operational performance. The average total cost of EA battery swap cases, which is £ 15.94 million, is higher than that of EA plug-in charge cases (£ 15.23 million). This is mainly due to the increased CAPEX for purchasing in-station EA batteries.

4.5. Microgrid energy technologies installed capacity

This section focuses on the installation capacity of airport microgrid energy technologies. Fig. 7 shows the variation in installed capacity of hydrogen fuel cells with two objectives (optimal cost and optimal operation) in 6 cases. As shown in Fig. 7, when the objective moves towards optimal microgrid operation, the hydrogen installed capacity increases from around 1 MW to around 8 MW, showing the importance of the hydrogen system for the airport microgrid operational performance. However, the hydrogen fuel cell system is so expensive that it will only be considered to be installed in large capacity when the operational performance of the microgrid becomes an essential objective. The necessities of the hydrogen system change in different cases, and it can be seen that the hydrogen fuel cell is of less importance in cases with V2G (Case 3 and Case 6) when considering a trade-off between two objectives, which could also be corroborated by the microgrid dispatch results presented in Section 4.2.

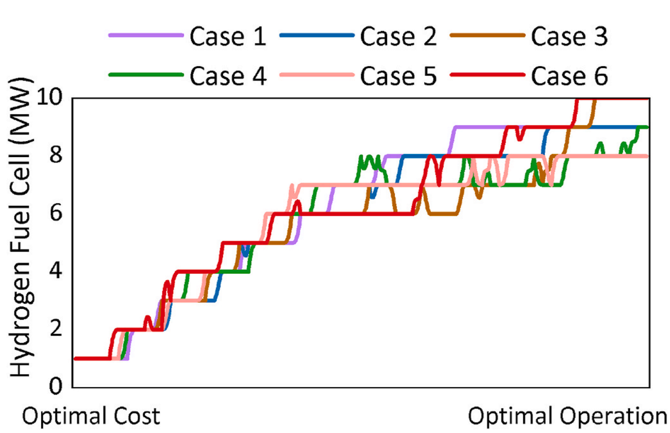

Fig. 7. Installed capacity of hydrogen fuel cell varying with two objectives in 6 cases.

4.6. Pareto Fronts and microgrid scoring

Fig. 8 illustrates the trade-off between microgrid resilience factors and costs across all six investigated scenarios. The high investment costs associated with EV charging result in higher costs for both G2V cases compared to scenarios without EVs. However, this cost difference is less pronounced in EA battery swap cases (Case 4 and Case 5) due to the reduction in peak demand during the day's peak hours. Microgrid resilience factors for scenarios without EVs are better than those for G2V cases, as the G2V strategy imposes an additional burden on airport demand. Nevertheless, the Pareto fronts and optimal solutions for Case 4 (EA battery swap without EVs) and Case 5 (EA battery swap with G2V) are nearly identical, indicating that the EA battery swap strategy effectively accommodates EV charging while minimising microgrid impact and financial strain. In both instances, V2G scenarios do not significantly improve resilience but tend to decrease overall costs. It is evident that the cases involving V2G technology exhibit higher resilience factors, indicating a greater reliance on the electricity supply from the main grid for these scenarios.

4.7. Annual analysis

Since this method focuses on a single design day, a comprehensive Annual operation analysis is conducted. Using the determined design capacity, the algorithm is executed for an entire year of renewable generation profiles. Supplementary Note 4 provides a detailed description of this analysis. Fig. 9 displays the box plot of one-year OPEX results across 6 cases. The results show that EA battery swap cases reduce the OPEX by approximately 4.2% comparing to EA plug-in charge cases. In EA plug-in charge cases, V2G can reduce the OPEX sharply by approximately 12.6% from Case 1. The box plot draws indicate that align with previous discussions: On average, the EA battery swap cases (Cases 4–6) can achieve lower OPEX compared to the EA plug-in charge cases (Cases 1–3); V2G cases (Cases 3 and 4) can reduce OPEX in comparison to the other cases. These results highlight the benefits of adopting an EA battery swap strategy and a V2G strategy.

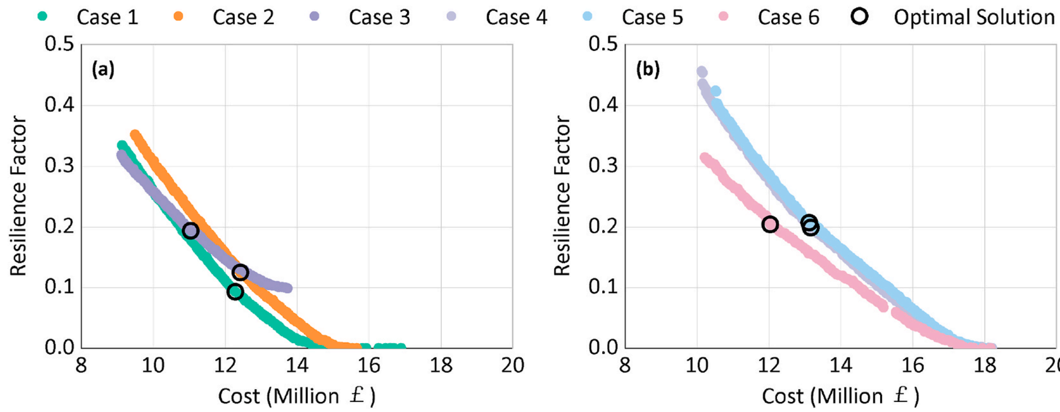

Fig. 8. Pareto fronts of different cases.

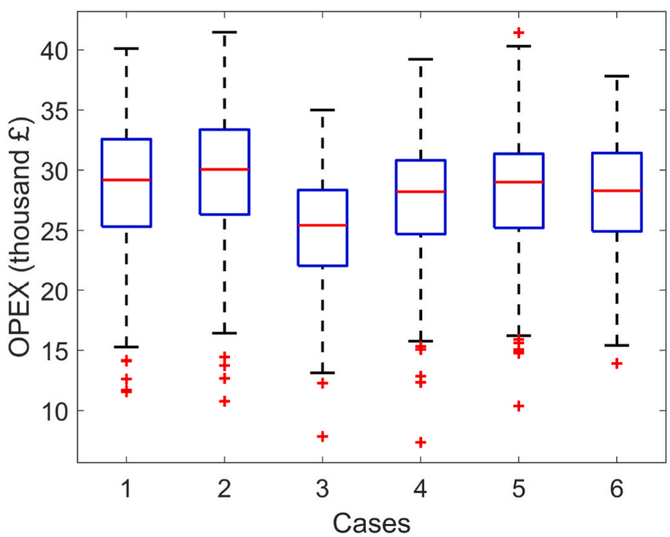

Fig. 9. Box plot for daily OPEX results across 6 cases.

5. Conclusion

While the economic assessment and operational performance of microgrids have been widely investigated in the literature, airport microgrids that integrate with potential EA and parking lot EVs remain an unexplored segment. This study proposes a bi-objective infrastructure planning framework for the airport microgrids to accommodate parking lot EVs and EA coordinatively. The system design, EA and EV scheduling, and energy dispatch of airport microgrid are optimised considering the trade-off between two objectives of economic and operational performance (resilience factor). Two different scheduling strategies for charging EA are proposed and compared comprehensively. The results indicate that the adoption of V2G strategy can improve the airport microgrid economic and operational performance compared to G2V cases. More specifically, V2G cases can reduce 12.9% of OPEX compared to G2V cases. Similarly, the cost reduction of 20.4% is also observed in OPEX results for EA battery swap cases. Although EA plug-in charge cases outperform battery swap cases in terms of microgrid performance, battery swap technology remains promising due to its daily OPEX reductions and the guarantee of fully charged batteries prior to EA fleet arrival, minimizing the likelihood of service disruption. Annual analysis demonstrates that the implementation of V2G technology for both EA plug-in charge and battery swap options leads to lower average daily costs, along with a 12.6% OPEX reduction compared to the base case. Furthermore, EA battery swap cases prove to be more cost-effective than plug-in charging cases, achieving a 4.2% reduction in daily OPEX. Overall, the proposed optimisation framework enables airport microgrids to effectively and safely accommodate both EA and parking lot EVs, paving the way for more sustainable and economically viable airport operations.

These findings will help airport operators to make the decision on how to facilitate aviation electrification. Future works could further explore the impact of integration with more flexible demand resources into the airport microgrid, such as controllable thermal load, electric ground support vehicles, and electric air conditioning systems. Another suggestion for future work is to develop advanced technologies such as stochastic optimisation, robust optimisation, chance-constrained programming methods, and information gap decision theory to handle the uncertainties introduced by the EA and EV charging, electric flight punctuality, and the EV owners' behaviour.

CRediT authorship contribution statement

Zekun Guo: Investigation, Data curation, Formal analysis, Methodology, Roles, Writing – original draft, Writing – review & editing. **Bozheng Li:** Data curation, Investigation, Formal analysis, Methodology. **Gareth Taylor:** Funding acquisition, Supervision, Conceptualization, Writing – review & editing. **Xin Zhang:** Funding acquisition, Supervision, Conceptualization, Roles, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.etran.2023.100257.

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