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A Review of Unpredictable Renewable Energy Sources through Electric Vehicles on Islands

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Abstract. The development of new technologies such as renewable energy sources, energy storage devices, and electric vehicles has changed the structure of the distribution grid to an active grid with bidirectional power flow. This paper introduces the concept of a smart island and its challenges and an isolated smart microgrid mode. Furthermore, this review provides an overview of the challenges that the penetration of electric vehicles has on islands through various types of charging modes. Finally, it is analyzed the impact of vehicle-to-grid on islands and the decarbonization of transportation sectors.

Keywords: electric vehicles, micro grid, plug-in electric vehicles, renewable energy sources, smart island, vehicle-to-grid

1 Introduction

Islands play a crucial role because they have been described as ideal locations to develop and test new strategies and solutions that will drive the transition to the continent. Islands on small geographic proximity provide the potential for the development of 100% renewable island energy systems by developing their grid interconnections [1].

In the past, since power plants were utterly manageable while the load was unpredictable, the flexibility of the grid was provided by traditional power plants. Nowadays, due to the variety of renewable energy sources (RES), variability and unpredictability shifted to the generation side, and the opposite change happened to the flexibility agents. One possible solution to solve this issue is to introduce electric vehicles (EVs). Day by day, the number of electric vehicles on the road has been increasing. However, to meet the fundamental objective of EVs, reducing air pollution, reducing fossil fuel dependency, electricity storage, grid services, and an increase in energy security, the electric energy needed to charge the EVs must come from RES. Therefore, RES plays a crucial role in energy transition, although they are more likely to be used for demand supplements due to their high efficiency and environmental features [2].

EVs have brought about real advantages to the transportation system by charging their only energy user role to real-time active elements, such as Vehicle-to-Grid (V2G). V2G is introduced to minimize the heavy impact of EVs in smart islands, a concept that has been developed over time. However, integrating clean and renewable energy sources and integrating electric mobility will pose challenges to their grids. Their charging demand may impose a sudden charge on the grid and disrupt the systems' normal operation [3]. Therefore, this paper provides four types of battery charging: uncoordinated, coordinated, smart charging for Plug-in Hybrid Electric Vehicle (PHEV), and charging using photovoltaic for EV. In this section, the mathematical model of PHEVs charging types is presented along with the advantages and disadvantages that each one entails according to its functionality. The transition from fossil fuel-based economy and emissions to renewable approach the issue of climate change which is a crucial part addressed at the end of this article.

The rest of this paper is organized as below: Section 2 briefly introduces the concept of a smart island. The details of electric vehicle charging modes optimization are elaborated in Section 3, then Section 4 verifies the integration of V2G. Section 5 analyzes the impact of decarbonization of transportation sectors and Section 6 presents a discussion to the literature review. Finally, some conclusions are presented in Section 7.

2 The concept of Smart Island

A Smart island (SI) is the definition of an insular territory that can implement integrated solutions to manage infrastructures and natural resources. It is an area that is isolated from the main electrical grid, and it's known to provide its demand by using RES in a local manner [4]. Therefore, within the smart islands, it has been introduced a platform for the EVs to be charged and discharged without the use of a common grid.

2.1 Challenges of the smart island and the distributed optimization

Due to its isolation feature, the demand supplement problem is one of the main challenges of the smart island, but this issue can be handled by using RES. In [4], the authors investigated a multi-objective deep adversarial-learning-based approach to address the optimal energy management of microgrids. Here, the aim was to minimize the total cost, pollutant emissions, and uncertainty factors modeled using an effective scenario-based method.

The smart island usually faces several challenges due to its different load demands because it can not be supplied only by using transportations and microgrid systems. A way to resolve this issue is through the use of energy hubs (EH), as authors in [5] discussed. The EH is a multi-carrier energy system that includes different generation units based on several layers, multiple sources, and functions and can meet the load requirements using effective methodologies.

Based on the studies mentioned above, smart islands can be operated and managed on a centralized basis. However, centralized approaches lack flexibility as new devices are added to the system, which implies recalculation of the entire schedule. Additionally, these approaches are not yet economically justified, and if the smart island agents are operated independently, this will be a problem. On the other hand, the decentralized approach is already more flexible, and it is possible to add new devices and perform distributed optimization [6]. The distributed approach refers to the methods through which the optimal energy and operation management schemes are obtained by proper energy and data transactions between the agents. In the same paper mentioned previously [4], the distributed optimization is analyzed by using a primal-dual method of multipliers which has shown a better performance when compared to the alternating-direction method of multipliers. Here, distributed approaches have proven better than centralized methods in terms of robustness, low process time, and fewer communication links. The main advantages of distributed methods are higher convergence and decentralization, which reduces the risk of attacking the center and destroying the entire system.

2.2 A Smart island as an isolated smart microgrid

The microgrid is considered to be the most viable option for a small island power system. Microgrid (MC) is an independent electric system that includes distributed energy sources and electric loads in small electric grids. They can be operated in an islanded mode which provides higher reliability, higher power quality, and power loss reduction.

One of the critical primary challenges in MC is energy management for island modes. A radical change in the energy system is required to increase the use of RES and solve the carbon dioxide problem. Authors from [5] provided a newer model for the operation of the smart island, which is represented as an isolated smart microgrid integrated with smart transportation systems residing of EV and the smart EH. Due to the high uncertainty effects on the smart island operation problem, the point estimate method (PEM) approach is used to handle the uncertainties for EVs as one of the study cases implemented.

3 Electric Vehicles Charging Optimization Modes on Islands

Since the conventional demand for an electric vehicle is somewhere between 10 kWh and 100 kWh per charge, the cumulative charging of EVs will impact grid performance and stability. Given that EVs have a high capital cost, charging occurs at home or work during the evening and nighttime. Thus, isolated overloading of the grid may happen in the early stages of electric vehicle adoption.

One of the main concerns of electrification of the transport sector is the impact of EVs on isolated electric grids. Distribution transformers can quickly become overloaded since an electric vehicle can increase the charging place demand, which can lead to several problems [7]. Many charging modes are analyzed to minimize these issues. The overall operation of the microgrid has been divided into four operating modes: uncoordinated, coordinated, smart charging for PHEV, and charging using photovoltaic for EV.

3.1 The uncoordinated charging

The uncoordinated charging of a large number of EVs can compromise the grids reliability, security, efficiency and economy. In references [8, 9] it is assumed that PHEVs leave their home in the morning and return in the evening, which is around 6:00 PM. A probability distribution function (PDF) with a uniformly distributed feature to model this scenario is defined in (1).

$$f(ts) = (1/b - a) * a \leq ts \leq b, a = 18, b = 19 \tag{1}$$

where ts is the charging start time of the PHEV, a, and b are a constant for specifying the shape of a logarithmic spiral.

3.2 The coordinated charging

Coordinated charging or charge management is the simplest way to execute and is most suitable in the early stages of EV adoption. It is also ideal for low electric vehicle penetration rates. Also, in [8, 9], PHEV owners tend to charge PHEVs in low-demand hours, during off-peak hours. The charging time is delayed, mainly after 9:00 PM, where the market price is low. The probability density function models the second charging pattern, which can be defined by (2).

$$f(ts) = (1/b - a) * a \leq ts \leq b, a = 21, b = 24 \tag{2}$$

As was mentioned in [7], coordinated charging can be implemented using unidirectional chargers with programmable timers, which can be set to charge the vehicle at a predetermined time of day. This method can help ensure that no additional generating capacity is required, and it also minimizes the impact on the daily demand profile. Optimization of charging times can help reduce daily electricity costs, while coordinated charging can help flatten the load curve.

3.3 Smart charging

In smart charging (SC), access to data from the charging device is essential to implement SC technology. The EV and the charging device share connection data, and then the charging device shares the data with the charging station operator. However, this data is only shared with the charging station operator with the consent of the EV user. The only disadvantage in SC is its high complexity and cost [10].

Authors in [8] refer that the primary goal of the SC scheme is to schedule the charging pattern of PHEVs in the most beneficial way possible. Vehicle charging occurs when there exists a mutual interest between PHEV owners and utilities. In addition, the vehicle starts charging when there is over generation capacity available, and the electricity price is low. In equation (3), a normal probability density function is considered.

$$f(ts) = (1/(\psi * \sqrt{2 * \pi})) * e^{-1/2*(ts-\mu/\sigma)^2}, \mu = 1, \psi = 3 \quad (3)$$

where ψ is the covariance, and μ is the mean value of the signal strength data set, and σ is the standard deviation. The vehicle battery starts charging once it is plugged into the grid. Equation (4) models the probability distribution function of the daily driven miles on the vehicle.

$$f(m) = (1/(m * \psi * \sqrt{2 * \pi})) * e^{(-\ln(m) - \mu^2)/2*\psi^2)}, m > 0 \quad (4)$$

where m is the number of observations in a sample set with type H1 (where the signal source is an adversary).

Authors in [3] refer to the fact that smart charging vehicles are connected to the grid and allow charging and discharging of the batteries to reduce energy import and export while simultaneously reducing production from conventional power plants. The outcomes show an increase in smart charging on EVs and a reduction in hydrogen vehicles.

In [11] Islands of Vis, Korkula, Lastovo, and Mljet are investigated. Here the authors propose that interconnections of a group of islands can integrate the production from locally available RES. Besides that, EVs are connected to the grid using smart charging systems and the V2G concept, and those vehicles can be considered potential storage systems for variable energy production. The results, modeled with EnergyPLAN, showed that the interconnections increased the share of energy from RES and reduced the total excess of electricity production. At the same time, the V2G concept enabled the exploitation of synergies between sectors.

3.4 Charging using Photovoltaic

Out of many RES, the solar photovoltaic (PV) based charging station (CS) is easily accessible and a possible solution. The main goal of designed CS is to utilize the PV array energy maximally to charge EVs. Therefore, its controller is designed to operate CS in an island model.

In [12] it is presented a real-time energy management scheme for EV charging using photovoltaic (PV) in the Uligamo island's context. The charging algorithm provides a decentralized coordinated method based on the heuristic strategy to optimize energy flow within the microgrid. The results show that EV charging using a PV-based microgrid is more economical than the autonomous charging generator. Through this scheme, the burden on the microgrid is reduced significantly.

Despite the various advantages of using the PV array for EV charging, the solar irradiance variation affects the charging station operation. Authors in reference [13] have discussed the effects of irradiance variations on EV charging.

The effect of irradiance variation becomes worse if the charging station operates in only island mode. Since the solar PV array power is not available at night, the charging station needs to be assisted with the storage battery [14]. Even under a step-change in solar irradiance level, sudden connection and interruption of EVs do not affect the performance of the control and charging of other EVs.

4 Integration of V2G

The innovation of V2G has some advantages, features, cost-effectiveness, and technical needs. When an electric vehicle's battery reaches between 70% and 80% of its original storage capacity, it is considered insufficient for use. In this case, vehicle-to-grid services can be used [7]. Battery systems are essential to homeowners on the small islands since this method can reduce electric bills, improve reliability and offer security, especially in power outages due to natural hazards.

4.1 Impact of V2G and V2H penetration on islands

Extreme events can damage power systems, like causing power loss for many customers and long outage periods. Therefore, during such circumstances, an electric vehicle can be used to power a house directly, through vehicle-to-home (V2H) or injects energy back into the grid, through vehicle-to-grid (V2G), where EV serves as a mobile energy storage system [15]. In this case, the EV creates a balance in the network by discharging the energy stored in the battery during peak hours and recharging during offpeak hours [10]. In [16], Shin and Baldick optimize the V2H system to provide maximum "backup duration," meaning the time duration of V2H supports the residential load without experiencing a critical load reduction during island mode.

However, if the restoration continues, the amount of energy EVs can contribute to limited stored energy without local power generation. In [4] an emergency power supply strategy featuring scheduled EV charging isolated systems is proposed. Here, by replenishing batteries with secured energy sources, EVs can transport electricity to the island system. To solve this issue, an optimization problem, the genetic algorithm (GA), is formulated to maximize the adequacy of the isolated system offer during the outage period and minimize the total loss of load.

4.2 V2G Charging

Engaging in V2G services can shorten the useful life of the EV by increasing the rate of battery degradation through the constant changes between energy injection into the grid and consumption [10]. However, only services requiring large amounts of power that lead to a significant battery discharge depth can significantly reduce battery life.

In [17] the energy transition of Hawaii is analyzed by underlining the interconnection of RES, battery storage, and V2G as two of the main components of the future smart grid. Authors in [18] model the potential impact of PHEVs technology on the island of São Miguel, Açores. They considered this island as an example of an isolated island with high renewable energy potential but largely dependent on fossil fuels incurring high import costs. To this end, the authors employ The Integrated MARKAL-EFOM System (TIMES), where they discuss one-way grid to electric vehicles (G2V) charging strategies for different scenarios of electric vehicles with varying levels of PHEVs penetration and conclude that 32% of them from this island's vehicle fleet could be realized. The results obtained indicate that the PHEVs integration into the local grid system could become a reality since it bears the potential to yield significant benefits to the energy mix, reducing thus the environmental impact of their heavy fossil-fuel dependency through allowing more intermittent renewable energy onto the grid.

Authors in reference [19] analyzed the introduction of EVs in the Caribbean island of Barbados to ease the integration of RES with a predominance of photovoltaic. In this research, two EVs operation modes were analyzed: scheduled charge and V2G, concluding that V2G results are the best solution with the best marginal cost. Article from [20] study presented some insights about the impact of V2G on the island of Korcula. The outcomes show how EVs would increase the total electricity exchanged with the mainland without affecting the peak power exchanged. Likewise, reference [21] obtains similar and better results in terms of primary energy demand reduction. They realized from the scenarios made that the V2G scenario is the one with the lowest annual cost, demonstrating that Smart Energy Systems might offer economically better solutions.

5 Decarbonization of Transportation Sectors on Islands

To promote the decarbonization of transportation sectors, transitioning to EV should develop in tandem with increasing renewable generation. The combination of EVs and RES makes possible the reduction of the dependency on fossil fuels and of the gas emissions. However, it is noted that the decrease in emission values leads to an increase in the total planning cost [22]. Many electric vehicle owners are often motivated to decarbonize their energy consumption and invest in renewable energy systems that offset their household and electric vehicle use. Electric mobility must be carried out in conjunction with the energy sector to ensure that emissions are reduced.

Islands need alternative green energy scenarios to balance their high dependence on fossil fuel imports for electricity generation. In [23] authors made scenarios that included hydrogen and battery storage for small islands. Through configurations of energy systems using HOMER software, they demonstrated the decarbonization of electricity and road transport sectors in an environmentally sustainable way. Authors in reference [24] examined the case study of two islands in the Azores, Pico, and Faial islands, to outline possible paths for 100% renewable energy systems [25]. The outcomes show that considering the islands with independent power systems, Pico island can achieve the primary goal. However, Faial island only reaches 70%. On the other side, the island's connection allows one to accomplish a 100% renewable energy system in both islands.

In [8] authors used SC electric vehicles and V2G, reducing a large part of the hydrogen ones. They came to realize that smart charges in this scenario increase 15% of the total transport demand. On the other side, hydrogen vehicles witness a reduction of 45% in their use in the regional vehicle fleet. Besides that, the grid's capacity to battery connection must be extended to 3000 MW to make up for the growing number of vehicles that need charging and use these vehicles as storage units for electricity.

6 Discussion

The increasing impact coming from the combination of EV and RES makes it possible to reduce worlds pollution. Therefore, EVs are the perfect solution to solve smart island challenges. To solve these challenges, a microgrid system alongside with EH is the most viable solution on islands. Additionally, the microgrid system is managed through distributed optimization, which has proven to be better than centralized methods. To minimize the problems that EV penetration causes on isolated electrical networks, four charging modes are referenced. In table 1, it is possible to see a summary of the main advantages, disadvantages, and functionality of the operating modes discussed before. Overall, coordinated and uncoordinated charging modes have more disadvantages than smart charging since they can compromise the main grid. However, despite smart charging having a low electricity price and promoting a reduction of hydrogen vehicles, charging by using a PV is the most accessible and less polluting solution. The drawback is that charging through PV depends on solar irradiation variety, meaning there is no production at night. A way to counteract this disadvantage is by assisting EVs with a storage battery.

Table 1. Summary of Operation Modes.

Operating Modes	Functionality	Advantages/Disadvantages
Uncoordinated	PHEV leave their home in the morning and return in the evening, which is around 6:00 PM	Can compromise grid's reliability, security, efficiency, and economy
Coordinated	The charging time is delayed, mainly after 9:00PM	Can help ensure that no additional generating capacity is required and it also minimizes the impact on the daily demand profile
Smart Charging	The vehicle battery starts charging once it is plugged into the grid	The outcomes show an increase in the smart charging on EV and a reduction of hydrogen vehicles
Photovoltaic	Through the use of PV array energy maximally to charge EV	Easily accessible and a possible solution although it depends on solar irradiation variance

7 Conclusion

This paper provides solutions that improve the ability of the grid to cope with unpredictable RES in the insular contexts by using EV. Here, several solutions, such as uncoordinated, coordinated, smart charging for PHEV and charging using photovoltaic for EV have been made, concluding that battery energy systems through charging using photovoltaic for EV are the most used technologies in the islands. This review discussed the concept of a smart island platform for the EVs to be charged and discharged without using a typical grid, along with the several challenges they faced. Besides that, it examined the topic of EVs dealing with the different operating modes such as V2G, which is not very feasible since not enough developments have been found in order to create a battery technology necessary for the success of this mode of operation. The results depend on the island's size and the charging mode.

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