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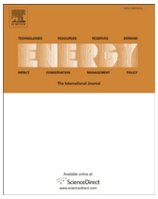

Impact assessment of electric vehicles on islands grids: A case study for Tenerife (Spain)

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ABSTRACT

The penetration of electric vehicles is a key instrument in the operation of smart grids. Their active participation in the electrical system is proposed as a tool to increase security of supply, successfully reducing the large differences that occur between periods of higher and lower electricity demand. This research presents an analysis of the vehicle-to-grid impact in low capacity electrical systems, as in the case of islands, aiming to establish a charge/discharge pattern that facilitates the penetration of electric vehicles in weak grids. In such a way, a comprehensive scenario needs to be assessed in order to obtain significant results to be applied not only in islands and outermost regions but also in scaled systems such as minigrids. To achieve this objective, a theoretical method for the efficient charge/discharge management of electric vehicles is proposed, defined by a multi-objective model based on criteria of mobility and technical requirements. The proposed model is applied to the island of Tenerife, which quantifies the electric vehicle penetration in a real case. The results show that grids in islands can assimilate “low” or “transition” penetrations of electric vehicles, so their use as storage systems allow to significantly reduce the amplitude difference between valleys and peaks of the electric energy demand curve and thereby to contribute to the efficient management of smart grids.

1. Introduction

In 2011, the European Commission (EC) adopted for the next decade a roadmap of 40 specific initiatives to build a competitive transport system that will increase mobility, employment as well as remove major barriers in key areas. Objectives will include, among others, the sharp reduction of conventionally-fuelled cars in cities [1] aiming to improve urban air quality by mitigating vehicular emissions in developing countries [2]. In this regard, clean and energy efficient vehicles have an important role to play [3], representing one of the most promising technologies for reducing oil use [4] and cutting emissions [5]. The transition to a smart energy future, where the integration of renewable energy sources (RES) has a leading role, starts reconsidering the entire energy framework including Demand Supply Management (DSM) and Distributed Energy Storage Systems (DESS), where the Electric Vehicles (EVs) would play an important role by integrating the storage capacity in a smart electricity network [6].

This framework has been reaffirmed in 2015 at the United Nations Conference on Climate Change, COP21, in Paris, where EVs are considered as a market-ready technology to fight against climate change [7]. In this sense, Spanish Government considers the EV as an industrial, technological, energy and environmental opportunity that opens up a pioneering field for the development of smart grids and mechanisms for DSM [8]. Since 2003 and as a result of this conviction, several policies have been developed aiming to promote EVs. In 2015, the Integral Strategy for the Promotion of the Energy Vehicle with Alternative Energy boost and encourages the acquisition of EVs, estimating a fleet of 150,000 vehicles in 2020, supported with a network composed by 1190 free access recharging points in public pathways [9]. These statements aim to achieve the aforementioned main objectives, established by the EC roadmap in order to reduce transport emissions, that otherwise would not be met.

One of the major benefits of EVs is that the flow of energy while the car is parked can be managed according to the electric system (ES) requirements [10]. The DSM allows, by charging EVs in valley

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Nomenclature

Acronyms

AC	Alternating Current
ASAI	Average Service Availability Index
DC	Direct Current
DESS	Distributed Energy Storage Systems
DG	Distributed Generation
DHS	Tarifa de Discriminación Horaria Supervalle (Super-valley hourly discrimination tariff)
DSM	Demand Supply Management
EC	European Commission
EED	Electric Energy Demand
EVSE	Electric Vehicle Supply Equipment
ES	Electric system
EU	European Union
EV	Electric Vehicle
GHG	Greenhouse gas
ITC	Complementary Technical Instructions
NEDC	New European Driving Cycle
PTEOTT	Plan Territorial Especial de Ordenación del Transporte de Tenerife (Special Plan for Transportation Planning for Tenerife Island)
RES	Renewable Energy Systems
SOC	State of Charge
TSO	Transmission System Operator

Sets

s	index of charging/discharging steps, $s = 1, 2, \ldots, S^{max}$
t	index of charging/discharging periods, $t = 1, 2, \ldots, 24$
v	index of electric vehicles associated to a power charge and charging time, $v = 1, 2, \ldots, V$
w	index of electric vehicles associated to a power discharge and discharging time, $w = 1, 2, \ldots, W$

Continuous variables

$D^{Ch}(v,t)$	total power including power demand of electric vehicle type v at period t (kW)
$D^{Dch}(w,t)$	total power excluding power supply of electric vehicle type w at period t (kW)
$P_s^{Ch}(v,t)$	power charge of electric vehicle type v in step s at period t (kW)
$P_s^{Dch}(w,t)$	power discharge of electric vehicle type w in step s at period t (kW)

Parameters

EED	Electric energy demand
D^{Ch}	total demand, including electric vehicle energy demand, when the electric energy demand value is minimum (kWh)
D^{Dch}	total demand, excluding electric vehicle energy supply, when the electric energy demand value is maximum (kWh)
N	total number of electric vehicle
$N_{Ch,v}$	number of electric vehicle type v
$N_{Dch,w}$	number of electric vehicle type w
$N^s_{Ch,v}$	number of electric vehicle type v charging in step s
$N^s_{Dch,w}$	number of electric vehicle type w discharging in step s
$S^s_{Ch,v}$	step of charge for electric vehicle type v
$S^s_{Dch,w}$	step of discharge for electric vehicles type w
t_{EEDmin}	time when the a electric energy demand value is minimum
t_{EEDmax}	time when the electric energy demand value is maximum
T^{Ch}	charging period available. It matches off-peak hours
T^{Dch}	discharging period available. It matches peak hours
$T_{Ch,v}$	charging time of electric vehicle type v
$T_{Dch,w}$	discharging time of electric vehicle type w
$P_{Ch,v}$	power charge of electric vehicle type v (kW)
$P_{Dch,w}$	power discharge of electric vehicle type w (kW)

periods, encouraging the overall performance of the ES by flattening the electric energy demand curve [11,12]. In this way, optimization of existing infrastructure is provided, facilitating a greater penetration of RES in low demand periods and minimizing risks that could destabilize the system [13]. Accordingly, the integration of EVs as DESS can contribute to reduce the difference in amplitude between valleys and peaks [14], becoming an active player in grid operation, contributing to a more efficient DSM and increasing RES penetration [15].

While most of power systems are large strongly interconnected, research focused on isolated or poorly interconnected systems, known as weak power grids, is getting increased attention [16]. In particular, in the case of an island, that is usually isolated from the mainland [17], stability is a major problem. These systems are relatively small and partially or fully equipped with small unit power generators and transmission grids poorly meshed with voltage levels lower than interconnected, resulting in low inertia systems. Therefore, the frequency variations from disturbances are considerably higher [18] being more difficult to fit the generation with the demand [19]. Consequently, in such grids, where generation units are oversized and peak-valley difference of the electric energy demand curve is significant [20], if a large amount of conventional generation is substituted by distributed generation (DG), such as RES, the safety and the stability of the power system can be compromised due to grid disturbances [21]. However, RES can penetrate optimally with DESS support, being the EV a convenient agent aiming to mitigate aforementioned issues that occur in island grids, as well as facilitate the reduction of GHG emissions [22,23].

According to literature, the proper integration of EVs into the grid needs to be complemented with a smart energy management within the approach of technical issues as well as dispatch costs and considering the inherent characteristics of each case. Within the purpose of implementation, research is focused on scheduling and optimization of charging/discharging profiles representing an useful tool to maximize the whole system performance from both demand and generation side [11,13,24–32].

In Ref. [11] a model of the home energy management structure is provided to investigate a collaborative evaluation of dynamic-pricing and power limiting based demand response resulting in a significant impact on the power pattern of a household and, accordingly, creating new peaks in former off-peak periods. In Ref. [24] a decentralized control method to schedule heterogeneous EV charging loads to fill the overnight load valley is presented, by calculating the probable aggregator control signal to make the submitted total charging load approach the desired total charging load. EVs update charging schedules individually and send updated

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