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An inclusive methodology for Plug-in electrical vehicle operation with G2V and V2G in smart microgrid environments

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ABSTRACT

Smart initiative concepts as smart grids, cities, and microgrids are redefining the electrical power system. This new scenario enables a completely new perspective of applications that lead to a path of general improvement of grid performance, in which the participation of plug-in electric vehicles has great importance. In this view, this work proposes a comprehensive operation strategy of plug-in electric vehicles for unbalanced smart microgrid environments. The first contribution is the grid-to-vehicle strategy based on buses availability of power whose primary objective is the maintenance of satisfactory operating conditions for the grid while controlling the plug-in electric vehicles charging. The second contribution relates to a holistic vehicle-to-grid coordinated approach, which is triggered in the event of microgrid islanding. The goal, in this case, is to assist the network by using the plug-in electric vehicles available stored energy. At last, the main contribution is obtained by the combination of both methodologies providing a comprehensive operation of plug-in electric vehicles for smart microgrids environments. The proposed method is designed for general three-phase unbalanced distribution systems with a wide range of resources and present versatility in the communication requirements. For validation, simulations are performed in a comprehensive unbalanced three-phase distribution system considering different disruptive scenarios faced by microgrids. The results indicate that the proposed methodology is satisfactory and ensure the operation of the microgrid within acceptable limits in both connected and islanded situations.

1. Introduction

Concepts such as smart grids, smart cities, and smart microgrids are redefining electrical power systems, especially at the distribution level. The first trend of development was focused on the establishment of proof-of-concept projects and identification of technologies boundaries. The second trend, now in progress, is the search for a definitive model capable of supporting the demands of the market [1]. This new scenario enables a completely new perspective of applications leading to a path of general improvement of the grid performance, in which the participation of plug-in electric vehicles (PEV) has great importance, due to its capacity to influence and assist the network in several levels.

To achieve those objectives supervised operation of PEVs on both perspectives grid-to-vehicle (G2V) and vehicle-to-grid (V2G) are fundamental. The G2V approaches may be separated in centralized and decentralized strategies [2–14]. Centralized strategies focus on the global optimization of the system, in which commands are sent from a central intelligence to each PEV unit [3–6]. Decentralized strategies, on the other hand, usually seek on maximizing user satisfaction, not being essentially thoughtful about a global performance of the system [7–13]. The application of local approaches involve fewer privacy concerns and require fewer investments leading to better scalability [14]. However, a massive penetration of PEVs can lead to undesired operative conditions if the global operative perspective of the system is not assessed. Possible violations include voltage operational limits and voltage stability [15,16], thermal limits of transformers and conductors, power quality and harmonic distortion [17], as well as losses and integration aspects [18].

The V2G methodologies may be categorized into technical and economic approaches. Technical strategies seek to support the system operation at both grid connected and islanded modes. This enables the operator to assist or completely perform processes as frequency [19–22], and voltage regulation [23,24], demand response [25,26], phase balancing, ancillary services, regulation of renewable generation intermittency and others [27–29]. Instead, economic approaches focus on maximizing the benefit of PEV owners concerning about the uncertainty of electrical tariff, remuneration for regulation capacity, user mobility and battery degradation [30–32].

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Nomenclature

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n	Bus number
N	Total number of buses
m	PEV's position at the bus
M	Total number of PEV units at the bus
ρ	Type of connection

Parameters

$CP^{available}_{Bus}$	Charging power available at the bus for PEVs' use
$CP^{available}_{PEVs}$	Charging power available for each PEV unit
CP^{max}_{PEVs}	Maximum charging power of each PEV unit
CP_{PEVs}	Charging power of each PEV unit
$D_{Remaining}$	Power relative to remaining demand
$\frac{D_{Remaining}}{DP^{max}_{Microgrid}}$	Percentage required of the actual maximum power available to be dispatched by PEV units to the system
$D^{Supplied}_{locally}$	Power relative to microgrid demand supplied by local generation
D_{System}	Power relative to microgrid demand
$DP_{available}$	Maximum dispatch power available
$DP^{available}_{Bus}$	Bus' maximum dispatch power available
$DP^{available}_{Microgrid}$	Microgrid's maximum dispatch power available
DP^{max}_{Bus}	Bus' actual maximum dispatch power considering O&T limits
$DP^{max}_{Microgrid}$	Microgrid's actual maximum dispatch power considering O&T limits
$\frac{DP^{max}_{PEV}}{DP^{available}_{Bus}}$	PEV's percentage stake on the bus' maximum available dispatch power
$DP^{max}_{technical}$	Maximum dispatch power that does not violate O&T limits
DP_{PEV}	Power dispatched by each PEV
$N^{A,B,C}_{PEVs1\varnothing\ charging}$	Number of PEVs in charging mode connected to a Level 1 or 2 single-phase chargers at the bus
$N^{A,B,C}_{PEVs3\varnothing\ charging}$	Number of PEVs in charging mode connected to a Level 2 or 3three-phase charger at the bus
$P^{available}_{Bus}$	Available power in the bus
P^{demand}_{Bus}	Bus load demand
	Rated power
P_{wt}	Wind turbine generation
PEV_{status}	1 - if PEV in charging mode, 0 - if PEV in standby
$SC_{Battery}$	Battery storage capacity
SOC	State of charge
SOC_{min}	Minimum state of charge allowed by the PEV owner
T_{INT}	Integration period
β	Loadability factor
$\Delta\lambda$	Increasing parameter
Φ	PEV-Chargers connection
ω	Wind speed
ω_{ci}	Cut-in velocity
ω_{co}	Cut-off velocity
ω_{r}	Rated velocity
α,κ,γ	Wind turbine model coefficients

Abbreviations

PEV	Plug-in electric vehicles
G2V	Grid-to-vehicle
V2G	Vehicle-to-grid
O&T	Operational and technical
SOC	State of charge

Although significant developments for PEVs operation are present in the literature, these methods formulation disregard global operative restrictions as voltage collapse, system technical limitations and lack a detailed unbalanced three-phase representation, which compromises their feasibility in an efficient distribution system environment. Furthermore, these applications designs are limited to either grid connected or islanded modes, is not possible to assess the mutual implications of these processes in each other. Notwithstanding, there is not available in the literature a methodology that employs PEVs to increase the service capacity of microgrids operating in islanded mode. To fulfill these gaps, this paper proposes an innovative and broad bidirectional operation of PEVs for smart microgrid environments in both grid-connected and islanded modes.

The first contribution is observed when operating connected to the main grid. In this case, the proposed grid-to-vehicle (G2V) strategy seeks a practical and simplified solution applying a methodology based on the power availability of buses. Its primary objective is the maintenance of satisfactory operating conditions for the grid while controlling PEVs charging to avoid undesired operative conditions that lead to local and global operative restrictions. Furthermore, if a failure in the bulk system leads to the microgrid islanding, the second novel contribution of this paper arises. It consists of a holistic vehicle-to-grid (V2G) coordinated approach, considering the constraints imposed by PEV units' owners and systems' operational and technical limitations to dispatch the PEVs stored energy correctly. The goal is to assist the network operation using PEVs available stored energy to increase the islanded network service capacity. The main and final contribution is the combination of both methodologies to provide a comprehensive operation of PEVs for smart microgrids environments with a detailed three-phase formulation and assess the mutual implications of V2G and G2V modes. The proposed methodology is designed for general three-phase unbalanced distribution systems and can operate with a wide range of resources such as renewable generation insertion, dispatchable generating units, variable demand, spot and distributed loads, voltage regulation, operational and technical limits, special constraints, and primary and secondary controls.

The authors recognize the complexity of the integrated operation of the separate aspects of a real distribution system and the PEV operation and hope that future work might further improve the overall methodology proposed. On the other hand, the relevance of this paper may be highlighted by some papers in the literature. In Ref. [33], the growing penetration of electric vehicles in power systems is focused. In that reference, a management system for charging electric vehicles is proposed. The goal is to maximize the lifespan of the batteries. Since the papers focus on a roadmap for the full implementation of electric vehicles, an algorithm to handle this problem is not proposed. Ref. [34] plays an essential role in the social discussion of an electric vehicle. The focus does not lie on the technical implications of electric vehicle. Rather than that, the authors claim that a broader debate must be embraced by communities, market players and researchers about the social