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Distributed energy resources management using plug-in hybrid electric vehicles as a fuel-shifting demand response resource

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ABSTRACT

In the smart grids context, distributed energy resources management plays an important role in the power systems' operation. Battery electric vehicles and plug-in hybrid electric vehicles should be important resources in the future distribution networks operation. Therefore, it is important to develop adequate methodologies to schedule the electric vehicles' charge and discharge processes, avoiding network congestions and providing ancillary services.

This paper proposes the participation of plug-in hybrid electric vehicles in fuel shifting demand response programs. Two services are proposed, namely the fuel shifting and the fuel discharging. The fuel shifting program consists in replacing the electric energy by fossil fuels in plug-in hybrid electric vehicles daily trips, and the fuel discharge program consists in use of their internal combustion engine to generate electricity injecting into the network. These programs are included in an energy resources management algorithm which integrates the management of other resources. The paper presents a case study considering a 37-bus distribution network with 25 distributed generators, 1908 consumers, and 2430 plug-in vehicles. Two scenarios are tested, namely a scenario with high photovoltaic generation, and a scenario without photovoltaic generation. A sensitivity analyses is performed in order to evaluate when each energy resource is required.

1. Introduction

The intensive use of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) will become reality in the near future [1]. The high prices of fossil fuels and the environmental concerns lead to new opportunities to increase BEVs and PHEVs penetration [2]. However, the intensive use of these types of vehicles introduces several changes in the power systems operation, mainly in distribution networks [3]. Additionally, other distributed resources, such as distributed generation (DG) and demand response (DR) will increase their penetration. To ensure the security and reliability of future power systems it is necessary to develop new approaches and methodologies for the distribution network management and operation.

Concerning the demand response programs, several programs have been proposed and used mostly in the United States as described in [4] and in Australia as illustrated in [5]. The DR programs increase the network operation flexibility allowing preventing critical situations mainly in peak periods when the networks are operated nearby their boundaries [6]. The use of DR events is a powerful resource to the system operators, but it also provides additional incomes (or energy bill reduction) from the consumer's point of view [7].

Most of the proposed DR programs are developed taking into account the characteristics of a specific target of "traditional" consumers like the industries, the commercial consumers or the domestic consumers [6]. Regarding the participation of electric vehicles (EVs) in DR programs, some developments have been made considering the participation of EVs in the existing DR programs. In [8] is proposed the inclusion of EVs in the participation of domestic consumers in DR programs and [9] evaluates the impact of price signals DR, namely the *time of use* and the *real time pricing*, in the EVs charging process. More focus in the system operator point of view, [10] analyses the EVs participation in a load shaping demand response strategy to avoid the power transformers congestion. However, in a near future, will be necessary the development of new programs specifically designed to the EVs due to the high flexibility provided by these resources. In this sense, this paper has three main contributions:

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Nomenclature

Parameters

Δt	duration of period t, e.g. 30 min corresponds to $\Delta t = 0.5$
η_c	energy efficiency in charge mode
η_d	energy efficiency in discharge mode
η_{Fuel}	efficiency in discharge mode considering the use of internal combustion engine of plug-in hybrid electric vehicle
B	imaginary part in admittance matrix (S)
c_A	fixed component of cost function (m.u./h)
c_B	linear component of cost function (m.u./kW h)
c_C	quadratic component of cost function (m.u./kW h^2)
c	resource cost in period t (m.u./kW h)
E	stored energy in the battery of vehicle at the end of period t (kW h)
$E_{Initial}$	energy stored in the battery of vehicle at the beginning of period 1 (kW h)
E_{Trip_Elec}	energy consumption during a trip in period t (kW h)
G	real part in admittance matrix (S)
L^i	set of lines connected to bus i
N	total number of resources or buses
R	ramp rate limit for the start-up or shut-down services
S_{Lk}^{max}	maximum apparent power flow in line k (kV A)
T	total number of periods
$\overline{U}$	voltage in polar form (V)
$\overline{y}$	series admittance of line that connects two buses (S)
$\overline{y_{sh}}$	shunt admittance of line that connects two buses (S)
z	total operation cost (m.u.)

Variables

θ	voltage angle
P	active power (kW)
Q	reactive power (kVAr)
S	apparent power (kVA)
V	voltage magnitude (V)
X	binary variable

Subscript

B	bus
BatCap	battery energy capacity
minCharge	minimum stored energy to be guaranteed at the end of period t
BEV	battery electric vehicle
Ch	charge process
ChMax	maximum charge power for the storage device
D	power demand at bus i
Dch	discharge process
Dch_Fuel	discharge process of the use of the internal combustion engine of plug-in hybrid electric vehicle
DchMax	maximum discharge power for the storage device
Deg	battery degradation
DG	distributed generation unit
DGMax	maximum power generation of *DG* unit
DGMin	minimum power generation of *DG* unit
DR_A	demand response program for loads with continuous regulation
DR_B	demand response program for loads with discrete regulation (on/off)
Fuel_Stored	storage energy in the fuel tank of plug-in hybrid electric vehicle
Fuel_Shift	reduction of the energy consumption with the trip in the plug-in hybrid electric vehicle
FuelThank_min	minimum quantity of fuel litters in the thank of plug-in hybrid electric vehicle
G	power generation at bus i
GCP	generation curtailment power
i , *j*	bus i and bus j
K	line
L, *Load*	load
MaxDR_A	maximum power of *DR* program for loads with continuous regulation
MaxDR_B	maximum power of *DR* program for loads with discrete regulation (on/off)
NSD	non-supplied demand
PHEV	plug-in hybrid electric vehicle
SD	shut-down
SEF	storage device (storage system, battery electric vehicle and plug-in hybrid electric vehicle)
SP	external supplier
SPMax	maximum power generation of external supplier
St	storage system
SU	start-up
Stored	stored energy in the battery of the storage device

Superscript

i	bus i
Max	upper bound limit
Min	lower bound limit

- Development of fuel shifting demand response programs applied to the PHEV. Fuel shifting DR means a replacement of the use of electric energy by the use of other fuel (diesel fuel or gasoline in the case of vehicles). The existence of an electric motor and an internal combustion engine (ICE) in the PHEV allows using different fuel sources to move the vehicle. In this case, the owners can connect the PHEVs to the electric network in order to charge their batteries to reduce the fossil fuel consumption. However, it is possible to reduce or to cut the energy charged in the PHEV without affecting significantly the users' comfort level. In fact, the PHEVs can only use the ICE, which would have as main disadvantages high cost and high greenhouse gas emissions. This way, the PHEVs should be remunerated according to the fuel shifting DR contract established with the system operator or with an aggregator. Another service that the PHEV can provide is the electric energy discharge from the ICE. This process is usually called vehicle-to-grid (V2G) and it considers the capability of charging the electric vehicles' batteries from the network and then, if required by the operator, discharging that stored energy in the batteries in the network. In the proposed methodology, the V2G concept is extended and the PHEV can use the ICE as a mechanical resource to generate electric energy into the battery, and then the battery will inject this generated energy into the power system. The use of this program should be avoided in covered car parks but can be used in the open ones;
- Integration of the proposed fuel shifting demand response programs in the energy resources management (ERM) algorithm used by the aggregator. The algorithm considers the management of a large set of distributed energy resources, namely DG based on several technologies, with and without "take-or-pay" contracts to avoid wind and solar generation curtailment; direct load control DR events considering discrete and continuous regulation loads; electric storage systems (ESSs), BEVs and PHEVs. Contracts with external suppliers are considered to balance the distribution network operation. The alternating