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Value of flexible electric vehicles in providing spinning reserve services

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HIGHLIGHTS

- Mixed integer linear programming model for provision of multiple services from electric vehicles.
- Flexibility benefits of electric vehicles in provision of spinning reserve and energy.
- Impact of different electric vehicles charging strategies on electric power system operation.
- Assessment of environmental and economic benefits under different energy mix scenarios.
- Assessment of wind curtailment reduction under different energy mix scenarios.

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ABSTRACT

As the share of integrated renewable energy sources (RES) increases, traditional operation principles of the power systems need to change in order to maintain reliable and secure service provision, on one hand, and minimal cost and environmentally friendly electricity generation on the other. The challenge of alleviating additional uncertainty and variability brought by new sources to the system operation is seen as defining both flexibility capacities and flexibility requirements through provision of multiple services. In this context the role of emerging technologies, such as electric vehicles (EV) and energy storage (ES), is recognized through their active participation in providing both energy and reserve service.

This paper elaborates on the benefits of active EV participation in multiple system services through various charging strategies. The presented mixed integer linear programming (MILP) unit commitment problem (UC) considers the capability of EV to provide primary, secondary and tertiary reserve as well as energy, however the focus is put on the benefits of EV providing spinning reserve services. The results clearly show benefits of multiple EV role to that of providing energy only. In addition the paper analyses multiple power systems, with regards to their energy mix, and recognizes how integration of EVs reflects on power system flexibility through metrics expressed as operational cost, environmental benefits and reduced wind curtailment.

1. Introduction

Electric power systems are experiencing tremendous transformation over the past few decades as the introduction of new low carbon technologies (LCT) brings changes in economic, environmental and regulatory aspects. One of key challenges in power systems today is the integration of renewable energy sources (RES) which are at the same time creating benefits to national energy policies (energy security, independence on import oil and gas), national economy (new jobs in rural communities) and to human health (decrease of greenhouse gas emissions and waste), but are also creating additional uncertainty and variability and challenging traditional principles of maintaining generation and consumption equilibrium. To compensate these imbalances the system operator is compelled to have enough reserve in every moment, meaning that the system must have enough flexibility. These services are provided by controllable, generating units through ancillary services forcing traditional fossil fuel based generators to operate in non-optimal working states, sometimes resulting in the overall operation cost and emissions increase despite the integration of clean energy sources [1,2].

With the uptake of LCT, new concepts for providing systems flexibility are emerging where both interconnections to other, more flexible power systems, or integration of new market participants, such as energy storage (ES), electric vehicles (EV) and multi-energy concepts [3], will change the paradigm of how low carbon power systems operate. Advancements in the field of energy storage technologies, improving their performance and reducing their investment cost, are making them a relevant future

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Nomenclature

Decision variables

$p_{t,i}^{g\_TP}$	thermal units generation
$p_{t,i}^{g\_HP}$	hydro units generation
$p_{t,i}^{g\_PS}, p_{t,i}^{p\_PS}$	pump storage generation/pumping
$p_{t}^{g\_WP}$	wind power generation
$p_{t,i}^{c\_EV}, p_{t,i}^{d\_EV}$	electric vehicles slow charging/discharging
$p_{t,i}^{f\_EV}$	electric vehicles fast charging
$f_{t,i}^{up\_TP}, f_{t,i}^{dn\_TP}, r_{t,i}^{up\_TP} r_{t,i}^{dn\_TP}$	thermal units primary(f)/secondary(r) up/down reserve provision
$f_{t,i}^{up\_HP}, f_{t,i}^{dn\_HP}, r_{t,i}^{up\_HP} r_{t,i}^{dn\_HP}$	hydro units primary(f)/secondary(r) up/down reserve provision
$f_{t,i}^{up\_PS}, f_{t,i}^{dn\_PS}, r_{t,i}^{up\_PS} r_{t,i}^{dn\_PS}$	pump storage primary(f)/secondary(r) up/down reserve provision
$f_{t,i}^{up\_EV}, f_{t,i}^{dn\_EV}, r_{t,i}^{up\_EV} r_{t,i}^{dn\_EV}$	electric vehicles primary(f)/secondary(r) up/down reserve provision
$q_{t,i}^{up\_TP}$	thermal units tertiary up reserve provision
$s_{t,i}^{\_EV}$	total energy in a cluster of EVs
$s_{t,i}^{arr\_EV}$	total energy in cluster of EVs arriving to the charging stations
$s_{t,i}^{leav\_EV}$	total energy in a cluster of EVs leaving the grid
$p_{t}^{f\_EV}$	percentage of fast charging EVs
$x_{t,i}^{c\_EV}$	number of EVs charging
$p_{t}^{sh\_WP}$	curtailed wind power
$c_{t,i}^{\_TP}$	total thermal power plant cost
$c_{t,i}^{\_HP}$	total hydro power plant cost

Input parameters

P_{t}^{d}	power demand
F_{t}^{up}	primary up reserve requirements
F_{t}^{dn}	primary down reserve requirements
R_{t}^{up}	secondary up reserve requirements
R_{t}^{dn}	secondary down reserve requirements
Q_{t}^{up}	tertiary up reserve requirements
$P_{t}^{\_WP}$	potential wind power generation
$R_{t}^{EV\_0.5h}, R_{t}^{EV\_4h}$	secondary and tertiary reserve requirements increase caused by uncontrolled EVs charging
$\sigma_{t}^{sl(0.5h)\_EV}, \sigma_{t}^{sl(4h)\_EV}$	EVs uncontrolled charging standard deviation for secondary and tertiary reserve
$\sigma_{t}^{(0.5h)\_WP}, \sigma_{t}^{(4h)\_WP}$	wind power standard deviation for secondary and tertiary reserve
$N_{\tau,i}^{arr\_EV}$	number of EVs arriving (plugging in) to the grid
$N_{t,i}^{g\_EV}$	number of EVs connected to the grid
$N_{t,i}^{leav\_EV}$	number of EVs leaving the grid
Ni_TP	number of thermal technology types
Ni_HP	number of hydro technology types
Ni_PS	number of pump storage technology types
Ni_EV	number of electric vehicles types
σ^{d}	power demand standard deviation
P^{gmax}	the biggest online unit in power system
$C_{i}^{UCH\_EV}$	time needed to fully charge EVs at full power
$\eta_{i}^{c\_EV}$	EV charging efficiency
$\eta_{i}^{d\_EV}$	EVs discharging efficiency
Δt	time period (0.5 h) for energy calculation
$S_{i}^{0\_EV}$	energy conserved in (all) EVs in time step zero
$S_{i}^{min\_EV}$	the lowest SOC value for one EV
$S_{i}^{max\_EV}$	the highest SOC value for one EV
$S_{i}^{cons\_EV}$	energy conserved in one EV which arrives to the grid
$S_{i}^{minc\_EV}$	the lowest allowed SOC in EVs leaving the grid
$P_{i}^{fmax\_EV}$	fast charging power maximum
$G_{i}^{\_EV}$	total number of EVs
$P_{i}^{max\_EV}$	slow charging power maximum

Abbreviations

BS	battery systems
CCGT	Combined Cycle Gas Turbine
CHPP	Conventional Hydro Power Plant
CoInTh	conventional inflexible thermal system
EPS	electric power system
ES	energy storage
EV	electric vehicle
FlTh	flexible thermal system
G2V-NR	grid-to-vehicle without reserve provision capabilities
G2V-YR	grid-to-vehicle with reserve provision capabilities
HP	hydro power
HyTh	Hydro Thermal system
InTh	inflexible thermal system
LCT	low carbon technologies
LoInFl	low carbon inflexible thermal system
MILP	Mixed Integer Linear Programing
NO-EV	Mode without Evs
NPP	nuclear power plants
OCGT	Open Cycle Gas Turbine
PS	pump storage
RES	renewable energy sources
RoR	run-of-river
SO	system operator
SOC	state-of-charge
TP	thermal power
TSC	Total System Cost
TSE	Total System Emissions
UC	unit commitment
UCH-NR	uncontrolled charging without additional reserve requirements
UCH-YR	uncontrolled charging with additional reserve requirements
V2G-NR	vehicle-to-grid without reserve provision capabilities
V2G-YR	vehicle-to-grid with reserve provision capabilities
WPP	Wind Power Production

flexibility provider as can be found in [4–7]. Microgrids are another promising concept where, by aggregating groups of geographically close loads and generators, the focus is shifting from centralized service provision to local, more system independent as described in [8,9]. However, currently the only integrated concept is that of demand response programs which includes changes in electric consumption by end-users in response to changes in electricity prices throughout day [10,11]. This concept has the potential to increase the systems flexibility by providing reserve to power systems in exchange for lower cost electricity for the end-users.

The focus of this paper is highlight the benefits of controlled electric vehicles charging which can be considered as a combination of all those aforementioned concepts; the battery on board acts as a storage unit, while a parallel can be drown between