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Incorporating short-term topological variations in optimal energy management of MGs considering ancillary services by electric vehicles

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ABSTRACT

This study proposes a well-defined energy management system (EMS) intended for smart microgrids (MGs) operational management. The proposed EMS aims at optimal allocation of active elements including electric vehicles (EVs), distributed generations (DGs), and responsive loads (RLs). To avoid the adverse effects of EVs' burden, a price-sensitive priority-based smart charging approach is outlined. As an innovative point, the potential of EVs in providing ancillary services such as reactive power provision is addressed in improving the MG's techno-economical performance. Moreover, the infield automatically controlled switches (ACSs) are accommodated to yield in optimal hourly reconfigurations. This practice would definitely impinge on the scheduling patterns of active elements and enhance the performance of the MG. Furthermore, the effects of reconfigurations and EVs' reactive power processes are explored on the capacity release of DGs, EV reliance, and imported power from the upper grid. The released/unallocated capacities are offered as reserve resources for undertaking the renewables' intermittency and load forecasting uncertainties. The proposed approach is formulated as a mixed-integer nonlinear programming problem and tackled based on time-varying inertia weight factor particle swam optimization. A medium-voltage MG is put under numerical analysis to assess the performance of the proposed EMS. Results are discussed in depth.

1. Introduction

Due to more strict regulations on reducing the consumption share of fossil fuels and lessening the environmental pollution, some effective concepts such as emergent MGs are provoked in recent years. Such concepts are accelerating the wide-scale penetration of DERs and modern technologies including EV and DRPs. In this manner, numerous advantages are deemed which remarkably enhance the technical and economical metrics of the MGs [1,2]. Focusing on the envisioned theme, many researchers have strived on developing low-cost, dependable, and novel ideas for efficient management of these networks [3]. A medium-voltage MG accommodates increased quantities of renewable energy resources, DGs, storage devices such as EVs, and the active consumers. It is also referred to an efficient power network that is capable of coordinating the operational planning of active elements and implementing the online short-term topological reconfigurations [4,5]. Such interactive applications are assisted through an advanced bidirectional communication infrastructure which is now an indispensable part of MGs [6,7]. All these supporting mechanisms, although so beneficial, are contributing in increased complexity of MGs' operational planning. Thereby, it is a pressing requisite to develop intelligent EMSs to undertake such sophisticated decision making problems.

In this context, some researchers have proposed efficient methodologies for daily operational scheduling of MGs affording either the operational costs minimization or enhancing the technical features of the system. A short-term operational scheduling of active elements such as DGs and external exchanges through the upstream grid is suitably tailored in Refs. [8,9]. Results demonstrate a noticeable reduction in overall operational costs. To make further economical improvements, Borghetti et al. have analyzed the possibility of higher renewable penetrations in active networks [10]. More in this field, some researchers have made benefit of deploying DRPs with end-side consumers. Among these, authors in Ref. [11] have recorded remarkable monetary savings through the

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Nomenclature

Indices, sets, and symbols

v, Γ	Index and set of EVAs.
m, M	Index and set of EV manufacturer.
t, T	Index and set for time intervals.
u, U	Index and set of upstream grid substations.
i, j, B	Indices and set of buses.
g, G	Index and set of DGs.
l, L	Index and set of RLs.
a, A	Index and set of ACSs.
f, F	Index and set of feeders.
$\vert \; \vert$	Symbol for the magnitude of variables.
$\_, \bar{}$	Symbols for minimum and maximum limits of variables.

Parameters

$P_{EV}^{Ch}, P_{EV}^{Dch}$	Charging and discharging power of each EV from a specific manufacturer.
P^D, Q^D	Active and reactive power demands at each bus.
ρ^{UG}	Electricity price from upstream grid.
ρ^{RL}	Price of power reduction for RLs' participation.
SU, SD	Startup and shut down costs of DGs.
a, b, c	Cost function coefficients of DGs.
Y, θ	Admittance phasor in feeders.
S^{UG}	Apparent power transfer through upstream grid.
S^f	Apparent power transfer through feeders.
PF^{RL}	Power factor for RLs.
η^{Ch}, η^{Dch}	Charging and discharging efficiencies of EVAs.
$\varphi_e, \varnothing_e$	Caps for available energies of EVAs and EVs, respectively.
N_B, N_F	Total number of buses and feeders.
N_{ML}	Number of main loops.

Variables and functions

N_{EV}	The number of charged/discharged EVs from a specific manufacturer.
k_{Ch}^{EVA}	An auxiliary variable to control charged burden of EVA.
k_{Dch}^{EVA}	An auxiliary variable to control discharged energy of EVA.
C^{UG}	Cost of Electricity from upstream grid.
C^{DG}	Cost of Electricity from DGs.
C^{RL}	Cost of Electricity from responsive loads.
C^{ACS}	Cost of ACSs switchings.
C^{EVA}	Monetary incentives paid for EVAs in V2G mode.
P^{UG}, Q^{UG}	Active and reactive power transfers from upstream grid.
P^{DG}, Q^{DG}	Active and reactive power dispatches of DGs.
P^{RL}, Q^{RL}	Active and reactive power provision by RLs.
P^f, Q^f	Active and reactive power transfers through feeders.
P^f, Q^f	Active and reactive power transfers through feeders.
E_{EVA}	Energy process by EVAs.
E_{Bat}	Available energy in each EV's battery.
$P_{EVA}^{Ch}, P_{EVA}^{Dch}$	Charging and discharging power of each EVA.
Q_{EVA}^{Proc}	Reactive power process by each EVA.
N_{ACS}^{Sw}	Number of switching operations by each ACS.
V	Voltage magnitude.
EVA_{Ch}	Binary variable representing that EVA is in charging mode.
EVA_{Dch}	Binary variable representing that EVA is in discharging mode.
EVA_{Idle}	Binary variable representing that EVA is in idle mode.
X, Z, W	Binary variables representing the startup and shut down status of DGs.

Acronyms

ACS	Automatically controlled switch
DER	Distributed energy resource
DG	Distributed generator
DRP	Demand response program
DRTU	Distribution remote terminal unit
EMS	Energy management system
EV	Electric vehicle
EVA	Electric vehicle aggregator
FRTU	Field remote terminal unit
G2V	Grid to vehicle
MG	Micro grid
MGO	Micro grid operator
PSO	Particle swam optimization
RL	Responsive load
RTU	Remote terminal unit
V2G	Vehicle to grid
WT	Wind turbine
ACS	Automatically controlled switch
DER	Distributed energy resource
DG	Distributed generator

incentives devoted for participation in load reduction schemes. Beforehand, the network topological reconfiguration has been thoroughly assessed in long-term fashions to obtain different operational objectives. Semiannual or seasonal power losses reduction [12], voltage profile improvement [13], reliability enhancement [14], and congestion management [15] could be named as such applications. This is while; the inclusion of ACSs has now realized the short-term network reconfigurations as a practical solution. This notion is recently implemented in few medium-voltage MGs [4,16]. In these surveys, the authors have underlined the significant monetary benefits and technical improvements of daily reconfigurations through the ACSs. In more details, the daily topological variations are shown to alter the optimal scheduling patterns of active elements and external interactions. However, these studies have dismissed the presence of EVs in MGs' territories which is a more promising element in recent networks.

Seeking for operational improvements, the concept of EVs intelligent participation is cared as well. Pang and Aravinthan have explored the coordinated management of EVs in daily demand side management processes [17]. Likewise, EV's functionality in minimizing the grid operational costs [18], providing reserve capacity for a MG [19], reducing the carbon emissions [20], power demand curve optimization [21], and reliability enhancement [22] is interrogated recently. Although the investigated literature provide good insights in view of charging action (grid-to-vehicle) or discharging task (vehicle-to-grid), however, the key functionality in majority of them involves the active power transfers. It is so well-understood that in a MG, the dispatchable DGs not only take part in active power provision, but also should provide the required reactive power for a safe operating scheme. A recent survey demonstrates that if the reactive power is suitably accommodated in the network, thereby, a higher capacity of DGs would be devoted in active power