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Range anxiety of electric vehicles in energy management of microgrids with controllable loads

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ABSTRACT

Recently-developed smart grids have a diverse range of load types that makes their energy scheduling different from conventional power systems. In this paper, an energy scheduling is proposed for smart grids to minimize operational cost and energy losses taking into account flexible (adjustable and shiftable) loads, which are used here as network resources. Special attention is paid to Electric Vehicles (EVs) as a sort of flexible loads. It is shown that the Vehicle-to-Grid (V2G) service may intensify power losses by charging and discharging EVs for multiple times and consequently, it is necessary to observe and optimize energy losses while using V2G. Range anxiety, which is one of main barriers to promote EVs, is formulated and optimized in order to address the concern of EV owners in depletion of battery energy and to encourage them to more actively participate in V2G service. Under the proposed scheme, EVs act as distributed energy storage systems to more employ renewables and also to make it possible to take the advantage of lower tariff electric energy from upstream networks. Results from examining the proposed method on a standard test system are presented and discussed.

1. Introduction

1.1. Motivation and aims

Electric Vehicles (EVs) can bring us diverse benefits such as reduction in oil dependency, mitigation of global warming, enhancement of energy security, better air quality, lower noises, and higher efficiency as a result of recent developments in smart grids. For instance, they can be helpful with their Vehicle to Grid (V2G) service. In view of the fact that EVs are parked most of times, they can act as distributed energy storage banks to store energy and feed it back later to the grid as V2G when it is needed. That is, EVs as active entities in electricity markets can shave load peaks and reduce price of electric energy by avoiding expensive peak generators. Furthermore, EVs can provide other ancillary services in electricity markets such as frequency regulation, spinning reserve, voltage stability and reactive power support. In addition, EVs can also open the space for renewable energy sources. Power generated by most renewables such as wind turbines (WT) and photovoltaic (PV) are intermittent and it may not be available when the network needs power. EVs can act as distributed battery storage units for these intermittent sources by storing their energy and feeding it back when needed.

On the other hand, in spite of their considerable benefits, EVs have some barriers. They can challenge electrical distribution systems as they may impose large electrical load blocks beyond the capacity of networks. In fact, if their charging task is not coordinated, EVs can worsen existing load peaks and intensify line overloads and voltage drops unless huge amount of funds is invested to upgrade electric power systems. Another hindrance for promotion of EVs is the concerns of their owner about running out of their battery in the middle of a trip as called Range Anxiety (RA) [1]. This can mostly happen when EVs offer V2G service and their battery is not charged fully by their departure time because of multiple charge/discharge cycles in the V2G. Because of the RA, EV owners may not be interested in participating in V2G and if this anxiety is not solved, the system operator loses the great storage feature of EVs as their concrete advantage. As another concern, V2G may increase network energy losses due to additional charge/discharge cycles of EVs as a result of extra power transfer cycles between EV and grid. In other words, benefits from V2G may be neutralized if energy losses are not monitored and controlled. It is noted that less attention in literature is paid to modeling of RA along with controlling V2G energy losses.

In addition to EVs, a microgrid has other types of electric loads classified as critical and flexible (adjustable or shiftable) loads. Energy management is important in microgrids to make them economical and stable. Critical loads, such as lighting to some extent, are inflexible and

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Nomenclature

Sets

B	Set of buses
T	Set of timeslots
V	Set of buses that have EV
U_i	Set of timeslots where EV i is plugged in
L_i	Set of timeslots that shiftable demand i is permitted to start

Indices

i,j	Index of buses
t	Index of timeslots

Parameters/constants

C_i^I	Cost of using interconnection at bus i of the microgrid (\$/kWh)
$C_{t,i}^E$	Energy price at bus i interconnection in timeslot t (\$/kWh)
ΔT	Timeslot duration (h)
K^A	Value of undelivered energy of adjustable demands (\$/kWh)
$P_{t,i}^{dA,des}$	Desired value of adjustable demand i at timeslot t (kW)
$P_i^{dA,min}$	Minimum of adjustable demand i at timeslot t (kW)
K_i^{RA}	Value of RA at bus i (\$/kWh)
SOC_i^{min}, SOC_i^{max}	Lower and upper limit of SOC of EV at bus i, respectively
C_i	Capacity of EV battery i (kWh)
C_i^{EV}	Battery wearing cost of EV at bus i due to V2G (\$/kWh)
$P_i^{EVc,max}$, $P_i^{EVd,max}$	Upper limit of charging and discharging power of EV at bus i (kW), respectively
ξ_i, η_i	Charging and discharging efficiency of EV charger at bus i, respectively
$W_{t,i}^{Trip}$	Energy consumed in trip by EV i at timeslot t (kWh)
$P_{ts,i}^S$	Required power for shiftable demand i at timeslot ts (kW)
$P_{i,t}^{W,max}$, $P_{i,t}^{PV,max}$	Upper limit of WT and PV generator at bus i (kW) in timeslot t, respectively
$P_i^{I,max}$	Rating of interconnection transformer at bus i (kW)
$P_{t,i}^{dC}$, $Q_{t,i}^{dC}$	Critical active (kW) and reactive (kVar) load, respectively, at bus i in timeslot t
S_{base}	Base power of the network for per unit values (kVA)
$Y_{ij}\angle\theta_{ij}$	Complex entry ij of the admittance matrix (pu)
V_i^{min}, V_i^{max}	Voltage limits of bus i (pu)
G_{ij}	Conductance of branch ij (pu)

Variables

$P_{t,i}^{Ip}, P_{t,i}^{Is}$	Purchased and sold active power at interconnection i at timeslot t, respectively (kW)
$Q_{t,i}^{Ip}, Q_{t,i}^{Is}$	Purchased and sold reactive power at interconnection i at timeslot t, respectively (kVar)
$P_{t,i}^{dA}$	Adjusted value of adjustable demand at bus i in timeslot t (kW)
$SOC_{t,i}$	SOC of EV at bus i in timeslot t
$P_{t,i}^{EVc}, P_{t,i}^{EVd}$	Charging and discharging power of EV i at times slot t (kW), respectively
P_t^{loss}	Microgrid total power losses at timeslot t (kWh
$x_{t,i}^{EV}$	1 if EV i is charged at timeslot t; otherwise 0
$W_{t,i}^{EV}$	Energy stored at EV i battery in timeslot t (kWh)
$x_{t,i}^S$	1 if the shiftable demand at bus i starts at timeslot t; otherwise 0
$P_{t,i}^{dS}$	Power drawn by shiftable demand at bus i in timeslot t (kWh)
$P_{t,i}^W$, $P_{t,i}^{PV}$	WT and PV power, respectively, generated at bus i at timeslot t (kW)
$x_{t,i}^I$	1 if power is purchased at interconnection bus i at timeslot t; otherwise 0
$P_{t,i}^g, Q_{t,i}^g$	Active (kW) and reactive (kVar) power injected by the upstream network to bus i, respectively, in timeslot t
$V_{t,i}\angle\delta_{t,i}$	Complex voltage of bus i at timeslot t (pu)
f_m, μ_m	Value and fuzzy membership of objective function m, respectively
f_m^{min}, f_m^{max}	Best and worst values of objective function m, respectively

then, they should be supplied by the network operator in the requested time. However, demand of adjustable loads such as air conditioning can be adjusted with consumer permission in their requested time in the range of their operation. Consequently, their energy consumption can be attuned to prevent intensified load peaks. Also, shiftable loads such as washing machines at smart homes can be shifted to less-congested hours of the power system over a time interval specified by the consumer to evade load peaks and decrease energy losses. EV loads can be classified as either critical or flexible depending on their owner preference. When the EV owner needs the vehicle to be charged in a short time interval, they are considered as critical loads. However, most EV owners plug in their vehicle at home or workplace and they need the EV to be charged by a later time; in this case, EVs are treated as shiftable loads which can be charged in a specified time interval.

Therefore, a smart grid aggregator needs efficient methods to supply emerging EV demands by properly managing flexible loads in existing power networks to take V2G advantages and to solve RA of EV owners at the same time. As a result, network operational costs are reduced, new investments are postponed, and the penetration level of renewable energies increases.

1.2. Literature review

Valuable research is carried out in literature to address energy management in smart grids considering EVs. For instance, authors in [2] proposed a method for power sharing management in microgrids considering vehicle-to-home (V2H). EVs are used as energy storage to mitigate intermittency of microgrids. In order to enhance stability of microgrid and to fulfill power sharing, proportional-integral controller of inverters is optimized. In [3], a bi-level optimization is proposed to optimally charge EV fleets using a sub-model for transport demand. The EV fleet model is used within the inner level of the bi-level optimization framework, where the aggregate charging power is optimized using dynamic programming.

V2G and the usage of EVs as distributed energy sources are researched in literature from different aspects. Authors in [4] proposed a four-threshold battery model for EV batteries in V2G from owner point of view to shave load peaks. In [5], V2G is used to manage energy imbalances of microgrids and a model is proposed for EV bidding strategy considering its battery degradation cost. V2G in [6] is used to provide spinning reserve using a control system in which battery condition and user convenience are considered. Authors in [7] proposed a charging scheme for EVs considering V2G in microgrids using game theory. In [8], a wind-powered EV charging station is studied with V2G capability. A maximum power point tracking is proposed for the charging station to capture higher wind energy. Using the proposed energy management model, surplus wind energy is injected to the grid for balancing of load demands. In [9], a bi-level methodology is proposed for EV parking lots where the aggregator maximizes its profit in the upper level through its interactions and in the lower level, the parking lot maximizes its profit considering preferences of EV owners. In some other works, EVs are assumed as distributed energy sources to enhance