Energy Conversion and Management 139 (2017) 20–32

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Distributed multi-agent based coordinated power management and control strategy for microgrids with distributed energy resources

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ARTICLE INFO

Article history:
Received 2 December 2016
Received in revised form 22 January 2017
Accepted 9 February 2017
Available online 24 February 2017

Keywords:
Electric vehicles
Multi-agent system
Distributed control
Inverters
Graph theory

ABSTRACT

In this paper, a distributed peer-to-peer multi-agent framework is proposed for managing the power sharing in microgrids with power electronic inverter-interfaced distributed energy resources (DERs). Recently, the introduction of electric vehicles (EVs) has gained much popularity by offering vehicle-to-home (V2H) technologies to support the sustainable operation of microgrids. Since microgrids often exhibit volatile characteristics due to natural intermittency and uncertainty, it is necessary to maintain the balancing of generation and demand through the proper management of power sharing. Therefore, the main purpose of this paper is to design an agent-based control framework to ensure the coordinated power management within the microgrids through effective utilization of EVs. The required agent communication framework is adhered to the graph theory where the control agents interact with each other using local as well as neighboring information and their distributed coordination effectively steers the proportional sharing of real and reactive powers among the inverter-interfaced EVs to maintain the stability of microgrids. The well known Ziegler-Nichols method is used to tune the proportional-integral (PI) controller of the inner current control loop within each individual control agent to perform necessary shared control tasks. A microgrid with solar photovoltaic (PV) and V2H systems is chosen to illustrate the results and it is seen that the proposed scheme improves the system performance in a smarter way through information exchange. Furthermore, the proposed framework is also validated by a comparison with an existing traditional approach and it is found that, the proposed scheme provides excellent robust and faster performance.

1. Introduction

In present days, the vehicle-to-home (V2H) technologies equipping with the battery energy storage systems (BESSs) are most valuable electrification schemes due to the ever growing global concerns of environmental issues. A number of electric vehicles (EVs) across the world are currently utilized as alternative distributed energy resources (DERs) along with the renewable energy sources (RESs) in microgrids. As a result, multiple power electronic inverters need to be installed in conjunction with those EVs to support the DC-AC energy conversion and deliver adequate amount of energy from the DERs.

When multiple EVs are integrated into the microgrids through power electronic inverters, the control and management of multiple inverters adversely suffer from stability problems and power quality issues due to the lack of proper coordination among the control devices. Moreover, as microgrids are composed of various control equipments, a lack of information exchange among different control schemes causes an imbalance between the generation and the load demand due to improper sharing of powers. However, a well managed power sharing strategy can be achieved at the expense of degrading the voltage and frequency regulation and vice versa [1]. Therefore, in order to provide reliable energy supply from the DERs, the real and reactive powers need to be shared proportionally from the EVs while maintaining the desired frequency and voltage within the microgrids as well as to keep the balance between the generation and the demand.

A number of centralized and decentralized droop control strategies have been proposed for inverter-interfaced EVs to achieve the desirable sharing of active and reactive powers [2–5] to maintain the voltage and frequency of the system. However, the conventional centralized droop control schemes reported several drawbacks due to a high cost of communication from central controller to all single equipment and these methods also posses risk of single-point failures. Moreover, often the existing hierarchical decentralized power management schemes [6–8] are unable to handle the fast-varying loads due to the slow dynamic response

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http://dx.doi.org/10.1016/j.enconman.2017.02.021
0196-8904/

Nomenclature

BESS	battery energy storage system
DER	distributed energy resource
EV	electric vehicle
ICT	information and communication technology
KCL	Kirchoff's current law
KVL	Kirchoff's voltage law
MAS	multi-agent system
PI	proportional integral
PV	photovoltaic
PWM	pulse width modulation
RES	renewable energy source
SOC	state-of-charge
V2H	vehicle-to-home
α	diode current constant
k	Boltzmann's constant
q	charge of electron
T_c	temperature of PV cell in Kelvin
A	ideality factor of p-n junction diode
I_s	saturation current
V_{pv}	output voltage of PV array
R_s, R_{sh}	series and shunt resistances
I_L	light integrated current source
s	solar irradiation
I_{sc}	short-circuit current
k_i	short-circuit current coefficient
T_{ref}	reference temperature of PV cell
N_s	number of cells in series
N_p	number of modules in parallel
R_0, R_1, R_2	battery resistors
C_1	battery capacitor
E_m	internal voltage of battery
m	modulation index in time-variant mode
I_1	current through the battery
τ_1	R_1 C_1
M_d, M_q	switching functions of generation modulation index in *dq*-frame
α_f	firing angle
I_d, I_q	*dq*-frame inverter current
R	line resistance
L	equivalent inductance of filter and line
ω	angular frequency
θ	angle between d-axis and magnetic axis of phase-a winding
E_d, E_q	*dq*-frame voltage
v_{dc}	voltage across the capacitor (C_{dc})
I_{dc}, V_{c1}	dc current and voltage
$S_{discharging}$	discharging energy
P_b	battery capacity
P_0, Q_0, V_0	nominal set point of ZIP load model
A_g	adjacency matrix
P_d	real power delivery
Q_d	reactive power delivery
P_L	real power load
Q_L	reactive power load

and also these methods have lack of broader information exchange among the subsystems. In last few decades, the distributed control schemes have gained much attention to coordinate the inverter-interfaced DERs in islanded microgrids [9–11]. However, the conventional distributed approaches viably require faster communications among the control schemes for proper sharing of powers within the system.

In recent years, the multi-agent system (MAS) has been established as one of the most popular distributed platforms to effectively manage the coordination and communication among the power electronic inverters in islanded microgrids. A multi-agent based control strategy for EV integrated energy system is proposed in [12] to manage the sharing of powers within the system. In [13], a mixed homogeneous and heterogeneous multi-agent based framework is proposed to achieve a faster coordinated control of voltage and frequency in islanded microgrids. In [14], a multi-agent based reinforcement learning algorithm is proposed for optimal power sharing in microgrids. Multi-agent based adaptive and cooperative voltage and frequency control approach with communication constraints is proposed in [15,16] for different network configurations. In [17], a multi-agent based hybrid supervisory control scheme is proposed for energy management system in microgrids. A decentralized multi-agent system based on non-cooperative game theory is proposed in [18,19] to provide a cooperative control framework for the complex power management in the autonomous microgrid systems. In [20,21], a communication assisted agent-based adaptive decentralized control scheme is proposed to control the inverter-interfaced DERs for sharing real and reactive powers in islanded microgrids. An intelligent coordinated control of a microgrid in both grid-connected and islanded modes using the multiagent system (MAS) technique is proposed in [22,23]. A consensus algorithm-based distributed hierarchical control for residential microgrids is proposed in [24] and in [25], a multi-agent based self-triggered communication enabled distributed control scheme is proposed.

Though the MAS approaches so far presented offer a number of benefits to control and manage the sharing of powers among the DERs, however, the existing MAS-based methods presented in [12–25] did not completely explore the system vulnerability due to a sudden change in the network configurations (perhaps due to natural or physical events) which often do not guarantee the proportional sharing of real and reactive powers to maintain the frequency and voltage of the system. In order to take the challenges over the existing and previous methods, an intelligent distributed peer-to-peer MAS is proposed for managing and controlling the DERS within the microgrids. The agent interaction adheres to a communication diagraph (using graph theory) through which control agents can exchange information to manage the coordinated control activities in a distributed manner and further determine their set points to regulate the real and reactive powers. In order to perform the necessary power control and management tasks, each control agent is considered to be embedded to a local proportional integral (PI) regulator-based inner current control scheme for each individual inverter of associated EV unit. The well known Ziegler-Nichols tuning approach [26] is used to select the gain of the controller whereas the agents use the information from local as well as neighboring EV units to facilitate the coordinated control of the *dq*-axis component of the inverter currents. However, the main three contributions of this paper are summarized below which distinguish the proposed framework from the existing traditional approaches:

1. The designed multi-agent framework provides a communication infrastructure to enable the information exchange among various control equipment for the effective and proportional sharing of real and reactive powers.