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Wolf pack hunting strategy for automatic generation control of an islanding smart distribution network ☆

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ABSTRACT

As the conventional centralized automatic generation control (AGC) is inadequate to handle the ever-increasing penetration of renewable energy and the requirement of plug-and-play of smart grid, this paper proposes a mixed homogeneous and heterogeneous multi-agent based wolf pack hunting (WPH) strategy to achieve a fast AGC power dispatch, optimal coordinated control, and electric power autonomy of an islanding smart distribution network (ISDN). A virtual consensus variable is employed to deal with the topology variation resulted from the excess of power limits and to achieve the plug-and-play of AGC units. Then an integrated objective of frequency deviation and short-term economic dispatch is developed, such that all units can maintain an optimal operation in the presence of load disturbances. Four case studies are undertaken to an ISDN with various distributed generations and microgrids. Simulation results demonstrate that WPH has a greater robustness and a faster dynamic optimization than that of conventional approaches, which can increase the utilization rate of the renewable energy and effectively resolve the coordination and electric power autonomy of ISDN.

1. Introduction

Generally speaking, a higher randomness and uncertainty of the active power and load disturbance of smart distribution network (DN) will be resulted in by the ever-increasing penetration of distributed generations and active load integration. Consequently, a massive information gathering and high computational burden will be emerged in the energy management system (EMS) [1,2], which brings in many new problems and challenges to automatic generation control (AGC) [3,4] of islanding DN (IDN). As a result, it is necessary to study the multi-agent system (MAS) decentralized coordinated control of AGC for IDN [5,6].

AGC can be normally divided into two procedures: (a) The total power references tracking of AGC, and (b) the total power references dispatch into each unit through optimization. In practice, proportional–integral (PI) controller is widely used in the total power references tracking of AGC in an IDN. In order to further improve the adaptability and control performance of AGC, an online particle swarm optimization (PSO)-based fuzzy tuning approach was proposed for frequency control in an AC microgrid [7]. Moreover, bacterial foraging optimization (BFO), PSO, genetic algorithm (GA) [50], and conventional gradient descent algorithm were applied to simultaneously optimize all the control parameters of microgrids by [8]. On the other hand, reinforcement learning has been investigated by the authors to achieve a smart generation control (SGC) of interconnected power grids such that the AGC dynamic control performance can be improved [9–14]. However, the aforementioned literatures are all based on centralized control, which requires a large amount of remote information thus the control performance may be unsatisfactory with a relatively slow dynamic response [15,16].

Recently, many researches have been undertaken to design a decentralized control for smart grid. A decentralized control was developed to improve the performance of a single-phase grid-interfacing inverter on component level [17], which can merely improve the local performance of an inverter. Additionally, a passivity-based control was proposed by [18] to solve the integration of a single distributed generation unit, of which the storage function is difficult to be constructed and it can only improve the local performance of a generator. In our published work [19], a

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Nomenclature

Constants

b_{ij}	the weight between v_i and v_j
a_i	coefficient of the generation costs
b_i	coefficient of the generation costs
c_i	coefficient of the generation costs
α_i	dynamic coefficient of the generation costs under power disturbance
β_i	dynamic coefficient of the generation costs under power disturbance
γ_i	dynamic coefficient of the generation costs under power disturbance
μ	metric of $\lvert\Delta f\rvert$
$1-\mu$	metric of the generation costs
γ	the discount factor
λ	the trace-attenuation factor
α	the Q-learning rate
φ	a variable learning rate
ς	a specified positive constant

Set

A	the set of action
S	the set of state
U	the set of mixed strategy
V	the set of node
E	the set of edge

Indices

k	index of iteration
i, j	index of agent running from 1 to n

Abbreviations

PI	proportional–integral
PSO	particle swarm optimization
BFO	bacterial foraging optimization
EMS	energy management system
AGC	automatic generation control
MAS	multi-agent system
GA	genetic algorithm
SGC	smart generation control
SARSA (λ)	state-action-reward-state-action (λ)
MDP	Markov decision process
LFC	load frequency control
VPP	virtual power plant
ISDN	islanding smart distribution network
$P_{\mathrm{G}i,\mathrm{actual}}$	the actual active power of the ith unit
$P_{\mathrm{G}i,\mathrm{plan}}$	the planned active power of the ith unit
$\Delta P_{\mathrm{error}}^{\max}$	the maximum tolerated power error of ISDN
$\Delta P_{\mathrm{G}i}$	AGC regulation power of the ith unit
Q^*	optimal function matrix
D	stochastic row matrix
$R(s_k, s_{k+1}, a_k)$	the agent's reward function from state s_k to s_{k+1} obtained under a selected action a_k
WPH	wolf pack hunting
CC	collaborative consensus
MA	multi-agent
ED	economic dispatch
DCEQ(λ)	decentralized correlated equilibrium Q(λ)
DWoLF-PHC(λ)	decentralized win or learn fast policy hill-climbing (λ)
FR	frequency regulation
MAS-SCG	MAS stochastic consensus game
MAS-SG	MAS stochastic game
MAS-CC	MAS collaborative consensus
DN	distribution network
IDN	islanding distribution network

Variables

$\tilde{U}(s_k, a_i)$	the average mixed strategy
ε	convergence coefficient
Δf	absolute value of the frequency deviation
ω	equal incremental rate of generation costs
$\omega_{i,\mathrm{lower}}$	minimum of the ith agent consensus variable
$\omega_{i,\mathrm{upper}}$	maximum of the ith agent consensus variable
$\omega_{i,\mathrm{virtual}}$	the virtual consensus variable
s	the state of system in MAS-SG
s_0	the initial state
visit(s_k)	the total number of state s_k from the initial state to the current state
a_g	a greedy action
a	action
ρ_k	the Q-function error of the agent at the kth iteration
$\Delta P_{\mathrm{G}i}$	AGC regulation power of the ith unit
$V^{\pi*}(s)$	optimal target state value function
$\pi^*(s)$	optimal strategy
R	reward
$e_k(s, a)$	the eligibility trace at the kth iteration used under state s and action a
$d_{ij}[k]$	the (i,j) entry of the stochastic row matrix $D=[d_{ij}]\in R^{n\times n}$ in the kth communication
x_i	the state of the ith agent in MAS-CC
v_i	node
δ_k	the estimate of Q-function error
C_i	the generation costs of the ith unit
C_{total}	the total actual generation costs
T_{step}	AGC decision time
ΔP_{Σ}	the total power reference
$\Delta P_{\mathrm{G}i}^{\min}$	the minimal adjustable capacity
$\Delta P_{\mathrm{G}i}^{\max}$	the maximal adjustable capacity
$\Delta P_{\mathrm{error}}$	the difference between the total power reference and the total regulation power of all units
B	weighted adjacency matrix
L	the topology of MAS
G	directed graph
$Q_k(s, a)$	the state-action value function

multi-step $Q(\lambda)$ was designed for optimal power flow of large-scale power grid. It is a single agent based approach, which needs a large amount of computation time as the agent number increases. Moreover, multiple equilibriums may emerge which would result in an undesired system instability. In contrast, this paper develops a robust decentralized controller of AGC, which can achieve a coordinated control between multi agents to improve the global performance of the whole system with an easy implementation. It is a multiple agents based approach which consumes a much smaller amount of computation time as the agent number increases compared to that of [19]. Furthermore, it only has a single equilibrium thus the system stability can be maintained. However, the above methods haven't taken the collaborative consensus (CC) of decentralized control systems into account, which cannot achieve a smart collaboration as each region is independent.

In MAS, a consensus among all agents is defined by a same selection of objective variable value through information exchanging with adjacent agents [20]. In the past decades, the application