Energy 101 (2016) 34–51

Contents lists available at ScienceDirect

Energy

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

Virtual generation tribe based robust collaborative consensus algorithm for dynamic generation command dispatch optimization of smart grid

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ARTICLE INFO

Article history:
Received 29 September 2015
Received in revised form
31 January 2016
Accepted 2 February 2016
Available online 27 February 2016

Keywords:
Virtual generation tribe
Decentralized collaborative control
Robust collaborative consensus algorithm
Virtual consensus variable
Consensus gain function

ABSTRACT

This paper proposes a decentralized collaborative control framework of autonomous VGT (virtual generation tribe) for smart grid. A VGT-CCA (VGT based collaborative consensus algorithm) is firstly developed to solve the dynamic GCD (generation command dispatch) optimization of the AGC (automatic generation control) under an ideal communication network. Then a novel CCA VGT-RCCA (VGT based robust CCA) is designed by introducing the consensus gain functions and virtual consensus variables, which provides significant robustness to a practical communication network consisted with switching topology, transmission delay and noise. The performance of VGT-CCA and VGT-RCCA has been evaluated on a typical two-area load frequency control model and the China southern power grid model, respectively. Simulation results verify the effectiveness of the proposed algorithms.

1. Introduction

In the past decades, smart grid has attracted numerous research works which has the merit of high efficiency and reliability, low pollution and costs, etc [1,2], while the performance of EMS (energy management system) determines the optimal operation of the smart grid [3].

As a crucial part of EMS, AGC (automatic generation control) of interconnected power grids aims to maintain the scheduled system frequency and tie-line power exchanges to their rated values [4]. At present, a large number of studies has been undertaken to investigate AGC for power grids, such as PI (proportional-integral) control [5], adaptive control [6], fuzzy logic [7], and RL (reinforcement learning) [8]. These approaches mainly focused on an optimal AGC for total generation commands in dispatch centers, while the dynamic GCD (generation command dispatch) optimization of the AGC has not been fully addressed.

To the authors' best knowledge, two centralized methods have been developed to tackle this issue. The first one is called the PROP (proportional) method, it assigns a fixed participation factor to each AGC unit which is proportional to the adjustable reserve capacity of that unit [9]. However, PROP method cannot provide satisfactory performance under various operation scenarios of power grids. The second one is known as the improved HQL (hierarchical Q-learning) algorithm [10], which can achieve the on-line self-learning. However, the improved HQL based dynamic GCD optimization has limited communication capacity and high computational cost due to the requirement of real-time information of the entire system. Hence, it is difficult to achieve the real-time control which performance may be degraded for large-scale AGC units.

Decentralized AGC [11] is a powerful tool to reduce the large information burden for the smart grid, which has been evolved into a large-scale CPES (cyber-physical energy system) consisting of a communication network and a power network [12,13]. Based on this concept, this paper proposes a novel AGC framework for the dynamic GCD optimization, which is called the decentralized collaborative control of autonomous VGT (virtual generation tribe), as specified by Fig. 1. The control area is divided into several regional grids based on their location, in which each grid is

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http://dx.doi.org/10.1016/j.energy.2016.02.009
0360-5442/

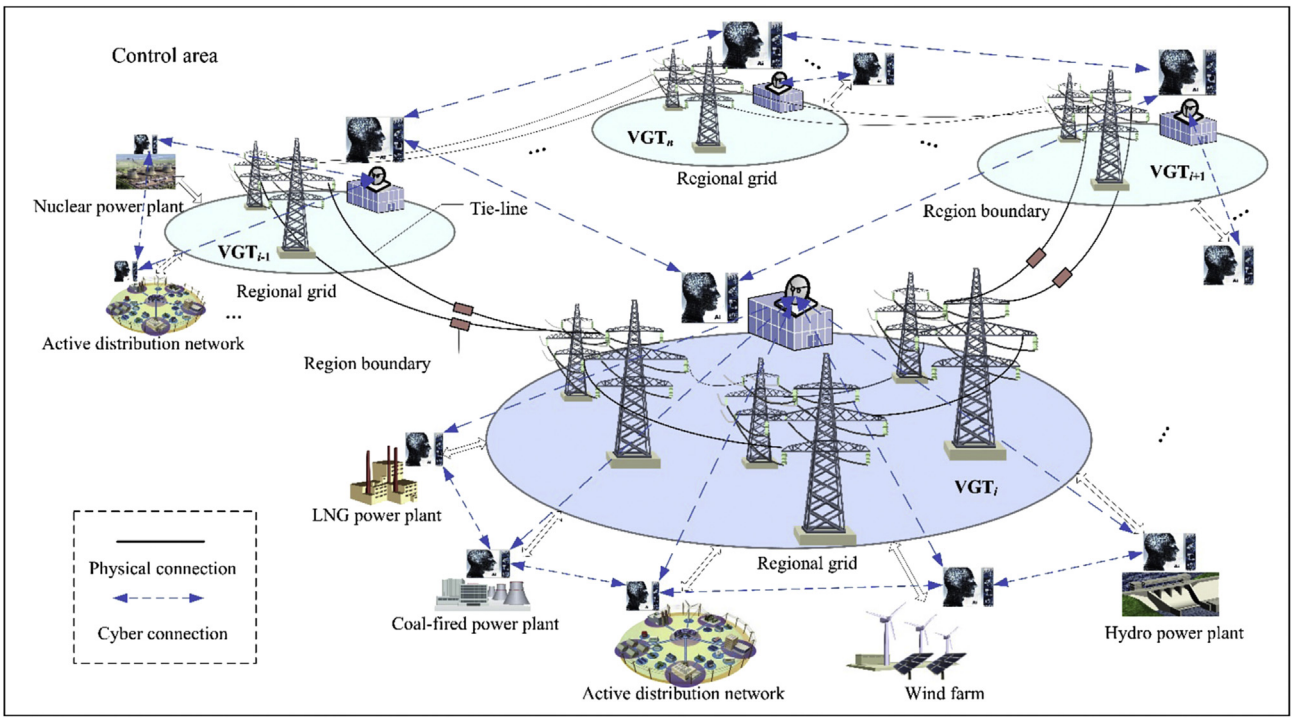

Fig. 1. Decentralized collaborative control framework of autonomous VGT.

equipped with a unique VGT including several plants and an ADN (active distribution network). Compared to the centralized AGC framework [14], the decentralized AGC can significantly reduce the dimension of dynamic GCD optimization and increase the communication capacity through the collaborations among the agents.

Under the proposed VGT framework, one crucial issue is how to achieve a consensus among all agents [15,16]. Various applications based on consensus algorithms have been undertaken to handle this issue, such as aviation control [17], animal behavior [18], and automatic control [19]. So far, few studies have been carried out in the power system control, particularly for the AGC. In Refs. [20–22], different consensus algorithms are proposed to solve the distributed ED (economic dispatch). An IWC (incremental welfare consensus) algorithm is presented by Ref. [23] for the energy management of a smart grid consisting with distributed generators and responsive demands. Recently, CCA (collaborative consensus algorithm) has been designed to achieve a rapid consensus, in which an agent can communicate with a limited group of neighbors to reach a consensus by some given state variables [17–23]. Thus a VGT-CCA (VGT based CCA) is firstly developed for the dynamic GCD optimization of an ideal communication network.

However, the switching topology, transmission delay and noise are ubiquitous in practical AGC communication networks [24–27], which may lead to a poor convergence or even divergence of the VGT-CCA. So far, several advanced consensus algorithms were proposed in Refs. [28–35] to consider the transmission delay and noise, in which the necessary and sufficient conditions are provided in Ref. [35] to solve the transmission delay and noise. On the other hand, many consensus algorithms were developed to address the switching topology [36–39], however, they have only taken the link failures into account while the unexpected exit of agents is ignored. In order to make the VGT-CCA feasible in a practical communication network, a VGT-RCCA (VGT based robust CCA) is then developed to simultaneously handle the transmission delay, noise, link failures and unexpected exit of agents.

Two examples have been carried out to verify the effectiveness of the proposed algorithms, in which the performance of VGT-CCA is evaluated on a typical two-area LFC (load frequency control) model under an ideal communication network, while the performance of VGT-RCCA is tested on the CSG (China southern power grid) model under a practical communication network.

The remaining of this paper is organized as follows. Section 2 proposes the decentralized collaborative control framework of autonomous VGT. The VGT-CCA and VGT-RCCA for dynamic GCD optimization are developed in Section 3. Simulation results are given in Section 4. The comparison of different algorithms is presented in Section 5. Finally, Section 6 concludes the paper.

2. Decentralized collaborative control framework of autonomous VGT (virtual generation tribe)

The conventional AGC scheme of a control area is implemented by two main control modules in the dispatch center: a controller of AGC and a dynamic GCD optimization. The former one aims to optimize the total generation command $\Delta P_{C\sum}$ obtained from the load disturbance under CPS (control performance standards). The latter one focuses on distributing the total generation command $\Delta P_{C\sum}$ among all AGC units.

Note that the dynamic GCD optimization is different from ED [40], as the AGC (secondary frequency control) and ED (tertiary frequency control) have different time scales and control objectives. ED aims to minimize the generation cost by distributing the system base load among all dispatchable generators without considering the CPS, which implementation period ranges from 5 to 15 min. In contrast, dynamic GCD optimization aims to allocate AGC regulation commands to balance the load disturbance, which has a much shorter implementation period ranging from 4 to 16 *s*.