Real-time coordination of distributed energy resources for frequency control in microgrids with unreliable communication

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ARTICLE INFO

Keywords:
- Distributed energy resources
- System frequency fluctuation
- Reliability
- Open communication network
- Cyber-physical systems

ABSTRACT

The management of distributed energy resources (DER) via control strategies mitigates frequency fluctuations stemming from the volatility of renewable resources and fluctuating power demand. Recently, open communication networks are integrated with the traditional control strategies to overcome the ubiquity of DER system and the lack of dedicated communication infrastructures. However, open networks are exposed to communication degradation and can reduce the control performance. This work investigates the reliability of the integrated DER system and open communication networks, i.e. the cyber-physical microgrid system, with reference to the frequency control in the face of communication degradation. Adequate control strategy is provided by a discrete PID controller tuned via multi-objective particle swarm optimization. The integrated system is tested on a real-time platform with different MAC protocols and open-communication-network architectures to investigate how the communication degradation reduces the frequency control performance. Simulation results demonstrate that transmission delays and packet dropouts jeopardize the ability of the integrated system to maintain the system frequency deviation within bounds. In particular, the use of Ethernet ensures higher reliability as compared to 802.11 b/g. Moreover, the impact of interfering traffic and of the percentage of used bandwidth on the PID controller performance reduction is assessed. The optimized PID controller can compensate for communication degradation and uncertainty conditions of the microgrid, and ensures robustness against unknown network configurations.

1. Introduction

The power sector is experiencing a structural trend towards decentralization stemming from the integration of large shares of renewable energy resources (RERs) [1]. This is fostered by distributed energy resources (DERs), which require the integration of power generation means located at or near the end-user side [2,3]. However, the stochastic nature of RERs and of the load demand induces system frequency fluctuations [4,5]. An effective control strategy is needed to keep the system frequency to its nominal value by balancing power generation and demand in real time. To this aim, automatic generation control (AGC) schemes are developed for damping frequency oscillations in distributed generation systems (DGS) [5–8]. AGC is performed by computing control signals based on the system frequency and delivering balancing inputs to various energy storage systems (ESSs) to absorb (release) the surplus (deficit) power from (to) the grid [8–10]. However, the ubiquity of DERs across wide areas and the complex structure of DGS hinder the development of dedicated communication infrastructures for the DGS with massive DERs [11–14].

Recently, the AGC has been integrated with the open communication network, due to low cost, high speed, simple structure and flexible access. Data exchanges among PMUs, generators and the control center are provided by the open communication network in the form of time stamped data packets [7,13–15]. Stable AGC depends heavily on the performance of the open communication network [7–9,15–20]. Cognitive radio networks, Cellular Networks, Local Area Networks (LAN), Wide Area Networks (WAN) and Wireless Local Area Networks (WLAN) are employed as open communication infrastructures in these networked control systems [10,11,14].

However, open communication networks are exposed to various types of degradation processes, i.e. network-induced time delays [8,9,18,19], packet dropouts [20,21], failures of communication infrastructure [22], uncertain communication links [23] and cyberattacks [24]. As a result, the measurement signals (control signals) received by the control center (ESSs or generators) degrade, effective AGC cannot be carried out and the system frequency response worsens [9–13]. Studying the performance of open communication networks is critical for understanding the occurrence of time delays and packet dropouts.
To this aim, medium access and packet transmission must be analyzed. The media access control (MAC) layer is the lower layer of the data link layer of the Open System Interconnection model, and it is responsible for moving data packets among network interface cards across the communication channels. Several MAC protocols, e.g. CSMA/CD (Carrier Sense Multiple Access with Collision Detection, Ethernet), CSMA/AMP (Carrier Sense Multiple Access with Arbitration on Message Priority, CAN) and 802.11 b/g (WLAN), prevent the collision of packets by employing random backoff algorithms. The impact of communication channels on the AGC performance and reduce the stability region [9, 10]. Packet dropouts refer to lost messages, which occupy network bandwidth but cannot reach destination. They affect the operations of DERs and the reduction of frequency fluctuations, particularly in uncertain network environments. Optimal feedback AGC regulators for DERs are investigated in numerous works for perfect communication networks and the impact of transmission delays and packet dropouts on the controller cannot be captured [28]. Robust PID controllers against constant or uniformly distributed time delays [8–11] are designed to cope with perturbations of the control parameters. Yet, constant or uniformly distributed time delays [8–11] are designed to cope with perturbations of the control parameters. Yet, constant or uniformly distributed time delays [8–11] are designed to cope with perturbations of the control parameters. Yet, constant or uniformly distributed time delays [8–11] are designed to cope with perturbations of the control parameters. Yet, constant or uniformly distributed time delays [8–11] are designed to cope with perturbations of the control parameters. Yet, constant or uniformly
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