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Load Frequency Control Strategy for Islanded Microgrid Based on SCQ(λ) Algorithm

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ABSTRACT

In the evolving landscape of power grids, where green transportation and intermittent clean energy play a crucial role, ensuring the security and reliability of the urban network is of utmost importance. However, the increasing volatility associated with these new energy sources poses a challenge to the traditional control methods. The large-scale integration of new energy in microgrids often leads to frequency instability and deviation in control performance standards. Addressing these issues, this paper introduces the SCQ(λ) algorithm, which accurately estimates the system's state to enhance controller capabilities. To evaluate the effectiveness of the proposed SCQ(λ) algorithm, the authors employ a load frequency control model in our simulation. In this model, they introduce various load change disturbances, including sine waves, square waves, and step disturbances to simulate realistic scenarios encountered in power systems. Throughout the simulation, they observe a significant reduction in frequency deviation in the case of step perturbation, with the deviation value decreasing by 0.0096.

KEYWORDS

Enhanced Learning, Isolated Microgrids, Load Frequency Control, Renewable Energy

INTRODUCTION

Currently, with the escalating global resource and environmental challenges, countries worldwide are increasingly embracing "dual-carbon" policies and initiatives. The emphasis on clean energy and electric vehicles signifies the prevailing trend towards upgrading the power supply infrastructure. To achieve the dual carbon objective, China is committed to constructing a new power system primarily reliant on new energy sources. However, the integration of a higher proportion of renewable energy sources brings about greater volatility and uncertainty in grid operations (Lam et al., 2020), which seriously affects the grid frequency stability and control performance standards (CPS). Microgrids offer a solution by enhancing the utilization rate of distributed new energy and effectively addressing electricity consumption challenges in remote areas, deserts, or islands. Moreover, microgrids provide a crucial avenue for integrating electric vehicles (EVs) and diverse forms of distributed green energy (Fan et al., 2022).

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In the context of load frequency control and regulation within microgrids, energy storage units play a vital role. In recent years, with the rapid popularization of EVs, these vehicles can be leveraged as controllable loads and distributed energy storage units (Chae et al., 2020; Iqbal et al., 2020). Through vehicle-to-grid (V2G) technology, EVs can absorb or transmit power back to the grid to regulate system frequency deviations in the event of grid disturbances or faults (Ziras et al., 2019; Chae et al., 2020). Literature (Li et al., 2019; Karkevandi et al., 2018) has established single-area and multi-area power system load frequency control models incorporating EVs. Various control strategies have been proposed, investigating the dynamic characteristics of system frequency control under these strategies. Simulation results indicate that EV involvement in power system frequency regulation can significantly enhance regulatory performance. However, the reliance on trial-and-error parameter adjustments in the Proportional-Integral control method employed in these models makes it challenging to achieve optimal control performance. Additionally, with the pursuit of the dual-carbon goal, extensive development and integration of new and clean energy sources have emerged as focal points of China's energy landscape (Chen et al., 2020). As a result, the existing controller outlined in the aforementioned literature needs to be enhanced to address the stochastic disturbances stemming from large-scale new energy integration in islanded microgrids.

The rapid development of emerging machine learning techniques such as reinforcement learning and deep learning in recent years has provided new methods and ideas to solve the above problems. Barbalho et al. (2022) designed a microgrid controller based on the DDPG algorithm to achieve microgrid frequency stabilization by changing the output power of energy storage elements. Fan et al. (2022) proposed a DQN-based load frequency control strategy for microgrid with electric vehicle islanding, which effectively solves the microgrid frequency fluctuation problem under wind disturbance. Wang et al. (2018, 2021) proposed the design of load frequency controllers based on Q-learning and deep Q-learning. It is worth noting that the above methods are derived from classical Q-learning, which updates the Q-function by approximating the maximum desired action value. However, a major drawback of this approach is the overestimation of action values, leading to suboptimal results due to local optimization. In order to address this issue, Hasselt et al., (2015) proposed a Double Q-learning (DQL) algorithm. DQL improves upon classical Q-learning by decoupling the action and state of the Q-function and can effectively solve the overestimation problem of action value in Q-learning. However, the method is not completely unbiased and may introduce an underestimation bias in action values while solving the overestimation problem. This bias could potentially hinder intelligent agents from exploring optimal strategies in the stochastic environment.

In order to solve the problem of overestimation and underestimation, the SCQ algorithm introduces a self-correcting estimator. The main concept behind this estimator is to utilize prior information to correct the estimation process, thereby enhancing the estimation accuracy. By employing the self-correcting estimator, the SCQ algorithm is better equipped to select the most appropriate value estimator. Thus, it can effectively avoid the problems of overestimation and underestimation and improve the estimation accuracy. However, directly adopting the self-correcting estimator for every update may lead to computational inefficiencies and waste of computational resources. Moreover, this approach fails to provide adequate convergence conditions for SCQ. Considering that recalculating the entire model for each update can result in prolonged training times and slow convergence, a solution is needed to overcome these challenges. In order to tackle the above problem, the eligibility trace participation update estimator is introduced in the paper. This estimator leverages the eligibility trace decay coefficient, denoted as λ, to track the involvement level of state-action pairs, associating past state-action pairs with the current update process. Additionally, the cumulative rewards of previous state-action pairs are also taken into account, enabling a more comprehensive evaluation of the value of each state-action pair. To balance past and current learning, a decay factor is employed to diminish the influence of earlier state-action pairs, and the trace value is periodically cleared. This approach

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