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Adaptation of fractional-order PI controller for a variable input interleaved DC–DC boost converter using particle swarm optimization with parametric variation

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ABSTRACT

The increasing demand for renewable energy integration has led to the development of advanced converter strategies to manage the inherent variability of renewable power sources. This paper presents a high-performance interleaved boost converter regulated by a fractional-order proportional-integral (FoPI) controller to ensure stable output voltage and power delivery under fluctuating input and load conditions. The FoPI controller parameters, including gains and fractional order, are optimized using particle swarm optimization (PSO) with the integral absolute error (IAE) as the objective function. The primary objective is to enhance the system's robustness against input voltage variations and load disturbances. The proposed PSO-FoPI controller is tested under different operating scenarios: (i) a fixed input of 150 V, (ii) an input variation from 150 V to 350 V, and (iii) a fixed 200 V input with output power demand variations between 8 kW and 12.25 kW. Also sensitivity analysis with changing parameter values of the converter and inclusion of step and ramp input disturbances, the performance of the controller is evaluated. MATLAB/Simulink simulations demonstrate that the PSO-FoPI controller effectively maintains the desired 400 V output and an average power of 10 kW while reducing transient effects and harmonic distortions. Comparative analysis with PI controller, tuned via Ziegler–Nichols and PSO techniques, highlights the superior performance of the proposed approach. The results confirm that the PSO-FoPI-controlled interleaved boost converter enhances stability and efficiency, making it well-suited for real-time applications utilizing renewable power sources.

1. Introduction

Amidst the ongoing increase in power demand, the limited availability of fossil fuels underscores the importance of renewable energy sources. As fossil fuel reserves diminish and their extraction becomes more challenging and environmentally detrimental, renewable energy sources such as solar, wind, and hydroelectric power offer a sustainable and environmentally friendly alternative. These sources are not only abundant and inexhaustible but also help reduce greenhouse gas emissions and mitigate climate change. Furthermore, advancements in technology and decreasing costs make renewable energy increasingly viable and cost-effective, providing a reliable solution to meet the growing energy needs while preserving natural resources for future generations.

Simply aggregating the sources is not the primary approach to fulfill the demand. Hence, it is necessary to employ a regulated approach to merge the sources to attain optimal advantages from renewable sources. Therefore, a variable or multi-input converter is required to improve the efficiency of utilizing renewable sources, as discussed by Navamani, Lavanya, Vijayakumar, and Navauga (2015). The converter being proposed is constructed using two interleaved legs. The topology utilizes a closed-loop PI controller with an appropriate tuning procedure to verify its performance. Compared to a traditional boost converter, an interleaved boost converter, as demonstrated by Dhople, Davoudi, Domínguez-García, and Chapman (2012), Prazenica, Frivaldsky, and Morgos (2019), and Lee, Lee, Cheng, and Liu (2000), offers several inherent benefits. These include reduced input current

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