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REVIEW

Implementation of sliding mode controller plus proportional double integral controller for negative output elementary boost converter

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Abstract This article presents a design, output voltage and inductor current regulations of the negative output elementary boost converter (NOEBC) operated in continuous conduction mode (CCM) using sliding mode controller (SMC) plus proportional double integral controller (PDIC). The NOEBC is a dc–dc converter that can provide high voltage transfer gain, high efficiency, and reduced output voltage and inductor current ripples in comparison with the conventional boost converter. Owing to the time varying switched mode operation, the dynamic characteristics of the NOEBC is non-linear and the designed SMC plus PDIC aims at enhancing the dynamic characteristics along with the inductor current and the output voltage regulations of the NOEBC. The proposed SMC is more appropriate to the essentially variable-structured NOEBC when represented in the state-space average based model. Here, the PDIC suppresses the steady state error and excellent initial start-up response of NOEBC in spite of input supply voltage and load resistance variations. The performance of the SMC plus PDIC is verified for its robustness to perform over a broad range of working conditions in MATLAB/Simulink models as well as in the experimental with the comparative study of a SMC plus proportional-integral-controller (PIC). Simulation and experimental results are presented.

Contents

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1. Introduction

In modern days, the dc–dc conversion topologies are developing very fast and it is more suitable for various medical equipment, power supply for telecommunication network, power supply for computer hardware parts, robot systems, defense electronic power supplies, renewable energy power systems, military applications and many more [1–3]. In theoretical point of investigations, the conventional dc–dc converters such as the buck, boost, buck–boost, Cuk, SEPIC (single-ended primary inductor converter), and Zeta converter can achieve a huge voltage transfer gain through an extremely high duty cycle [4–8]. However wretchedly, in real-time practice, which is limited due to the effect of power semiconductor switches, rectifier power diodes and the equivalent series resistance (ESR) of storage elements. Furthermore, the extremely huge duty-cycle operation of the converter will affect in a grave reverse-recovery trouble.

The super-lift technique (SLT) increases the output voltage stage by stage in geometric progression, whereas the negative output elementary boost converter (NOEBC) does the same with a simple formation [9]. The NOEBC is an attractive dc–dc converter topology, which converts the positive dc source voltage into negative dc load voltage. The intensive research has offered most new dc–dc converter circuit topologies reported in [10]. These converters in general have intricate non-linear models with parameters variation. The understandably better candidate in the family of dc–dc converters, the NOEBC, is well thought-out for this article study.

The most famous modeling methods for higher order dc–dc power converters are signal flow graph (SGF) and state space averaging methods [11–14]. The SGF method is simple but dynamic performance is still limited as high frequency components are averaged out in the model. It makes the controller unsuitable for large-signal dynamic control. The small-signal analysis of dc–dc converters with sliding mode controller (SMC) has been reported in [15]. It would not envisage the dynamic response of a switching converter in saturated region and works only for a particular best possible operating condition.

The realization of classical linear controllers namely, pro portional-integral-derivative (PID) or proportional-integral-c ontroller (PIC) for the outer voltage loop control has been well executed in [16–19]. However, these controllers are very sensitive to circuit parameter changes, and transform in working state, input supply voltage and load variations.

The victory of classical non-linear controller lies in performing superior against these problems as dc–dc converters are naturally variable structure systems (VSS) [20]. The controller of NOEBC must manage with their intrinsic nonlinearity and large input voltage and load variations, ensuring stability in any working condition providing fast transient and enhanced dynamic responses. Fundamentally, the SMC utilizes a high-speed switching control law to drive the nonlinear phase trajectory onto a precise surface in the state space, called the sliding or switching surface, and to keep it on this surface for all consequent time [21–25]. All these traditional based SMCs offer many merits over the linear PIC or PID controller; they provide stability even for large line and load variations, robustness, good dynamic response, and simple implementation.

Claim of SMC at variety of sliding surfaces for dc–dc converters has been well reported in [26–31]. However, these conventional SMCs are enforcing the system phase trajectory along with ideal sliding surface at infinite frequency. This is undesirable, as high operating switching frequency will result in excessive switching losses, inductor loss and electromagnetic interference (EMI) noise problems. The reduced order SMC for Cuk' dc–dc converter has been dealt [32]. However, this article discussed about the control of output voltage and supply current for Cuk' converter using SMC, which generated more initial start-up overshoots as well as dynamic operating regions. The reduced order based fixed switching frequency SMC for negative output elementary super lift Luo-converter has been well addressed in [33]. However, this article presented the control of output voltage, inductor current for selection of single integral based sliding surface, which resulted the more steady state error, large start-up settling time of the response, and large overshoots during the dynamic conditions and also difficulty controller implementation. Current distribution control for paralleled POESLLCs and output voltage regulation of NOBC using variable frequency based SMC has been well presented in [34,35]. But, these articles are considered the control of output current and output voltage for sensing all the