A Comparison between Classical and Advanced Controllers for a Boost Converter

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Abstract

DC-DC switching converters are well known for their versatility with wide range of applications. Such demanding applications are always required fixed voltage for of any changes on input or load side. Here, three different control topologies such as Classical PID controller, Sliding Mode Controller (SMC) and Internal Model Controller (IMC) have been implemented for achieving better performance and voltage regulation for Boost converter. In this work, the converter performances with PID controller is compared with IMC and SMC. The closed-loop performances of converter with these different control algorithms are compared in load and reference voltage disturbances. IMC behaves like a superior controller compare to other control algorithms for its better steady-state and transient responses. Here, computational results are reported for the verification purpose but the practical implementation is going on and that may be future scope of this presented work.

Keywords

Boost converter, PID controller, Internal Model Controller, Sliding Mode Controller.

I. INTRODUCTION

DC-DC switching converters have played significant roles in almost every domain of engineering application. Some most common applications of switching converters like as personal computers, active filters, inter connection of solar & fuel cells to grid, switched-mode power supplies (SMPS), efficient lighting and heating, high voltage DC power transmission (HVDC), traction motor control in electric vehicles, adjustable speed motor drives, telecommunication equipment, and many others [1].

Generally, the DC-DC switching converters have been controlled by pulse width modulated (PWM) current or voltage mode control with classical controllers like proportional (P), proportional-integral (PI), proportional-integral-derivative (PID) controller etc. These classical controllers can provide good closed-loop performance at the designed operating point. The design of classical controllers is required scrupulous trial and error method and that may be time consuming. However, such controller is applicable only for linearized plant model in majority cases, and that may restrict the zone of operation [3-4]. Most of the real-time applications are afflicted by different nonidealities such as switching nonlinearity, load disturbances, and parametric uncertainty. That's why sometimes the classical controllers may fail to maintain the regulations at desired levels of those switching converters. The DC-DC SMPCs are time-variant and highly nonlinear and for the effective implementation switching converters do not impart themselves with classical control strategies. Therefore, advance controllers are required for controlling DC-DC switching converters. In case of wide variation of system parameters, uncertainty & un-modeled dynamics of plant, nonlinearity *etc*. the controllers based on advanced control techniques are best suited [5]. The main advantage of these controllers is that the controllers have the ability to react with sudden changing in transient condition. There are different types of advance controllers like as hysteresis controller, sliding mode controller, internal model controller etc. [6-24]. The variable structure systems are the physical structured system that can be changed during time with respect to the structure control law. Due to the presence of switching action, the DC-DC SMPCs are inherently variable structure systems. So, these advance control techniques are well suited to control the DC-DC switching converters. These controllers are robust in nature over the converter's large parametric variation, load and line disturbances [15].

The main objective of this paper is to study & implement different advance control methods *like* sliding mode control (SMC), and internal model control (IMC) in DC-DC switching Boost converter. A comparative study between the performances of classical and advance control techniques is reported for DC-DC SMPCs under reference and load variations. From this study, it can be observed that the advance controllers provide better dynamic & steady-state performance, and robustness against system uncertainty, disturbances over the classical controller. The SMPCs which are controlled by the advance controllers show excellent transient performance with the disturbances. In advance control approach, a compensation network is not required for closed-loop like classical controller. Hence, the circuit is considered as lesser component count and small size in implementation with the fastest control performance. The motivation of this presented work is to design a better controller so that the performance of Boost converter can be enhanced even under disturbances.

II. BOOST CONVERTER

Boost converter is the most widely used DC-DC converter topology in battery chargers, hybrid renewable systems and other applications. Boost converter steps up DC input voltage to higher level DC output voltage. Different linear and nonlinear control approaches [12-24] are already executed in Boost converters. The schematic diagram of closed-loop Boost converter is shown in Fig. 1. The parameters of the proposed converter are ordered in Table I.

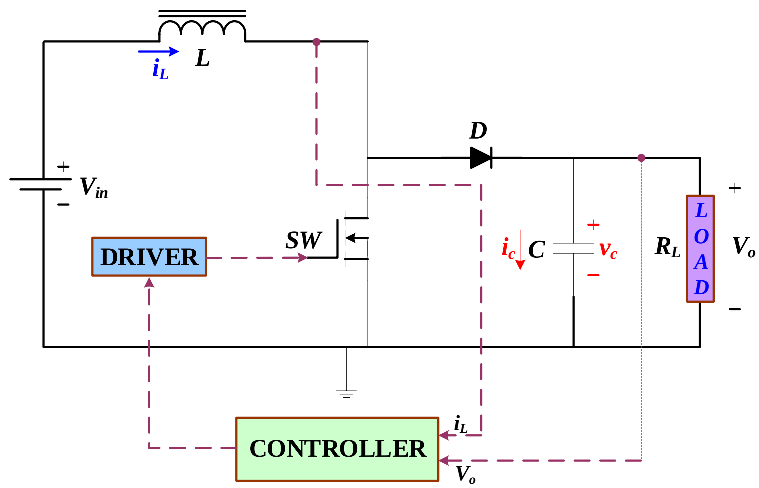


Fig. 1. Block diagram of Boost converter in closed-loop operation.

TABLE I. PARAMETERS OF BOOST CONVERTER

Circuit Components	**Values**
Input Voltage V_{in}	5 V
Output Voltage V_o	12 V
Inductance L	250 µH
Output Capacitance C	1056 µF
Load Resistance R	25 Ω
Switching Frequency, f_{sw}	20 kHz

A. *Transfer Function of Boost Converter*

The small signal modeling approach [1-4] is implemented for getting the transfer function of DC-DC switched-mode Boost converter. The output voltage to duty cycle averaged transfer function of converter is written in Equ.1.

$$T_p(s)=\frac{\tilde{v}_o(s)}{\tilde{d}(s)}=G_{do}\left(1-\frac{s}{\omega_{z-RHP}}\right)\Bigg/\left\{1+\frac{s}{\omega_o Q}+\frac{s^2}{\omega_o{}^2}\right\} \tag{1}$$

where,

$$\mathrm{G}_{do}=V_{in}\big/(1-D)^2;\ \omega_{z-RHP}=R_L(1-D)^2\big/L\ \text{rad/sec};\omega_o=(1-D)\big/\sqrt{LC}\ \text{rad/sec};Q=\omega_o R_L C$$

From the Eqn.1, it has been observed that a right-half plane zero presents in the transfer function of Boost converter. So, the effect of non-minimum phase problem has occurred in converter dynamics.

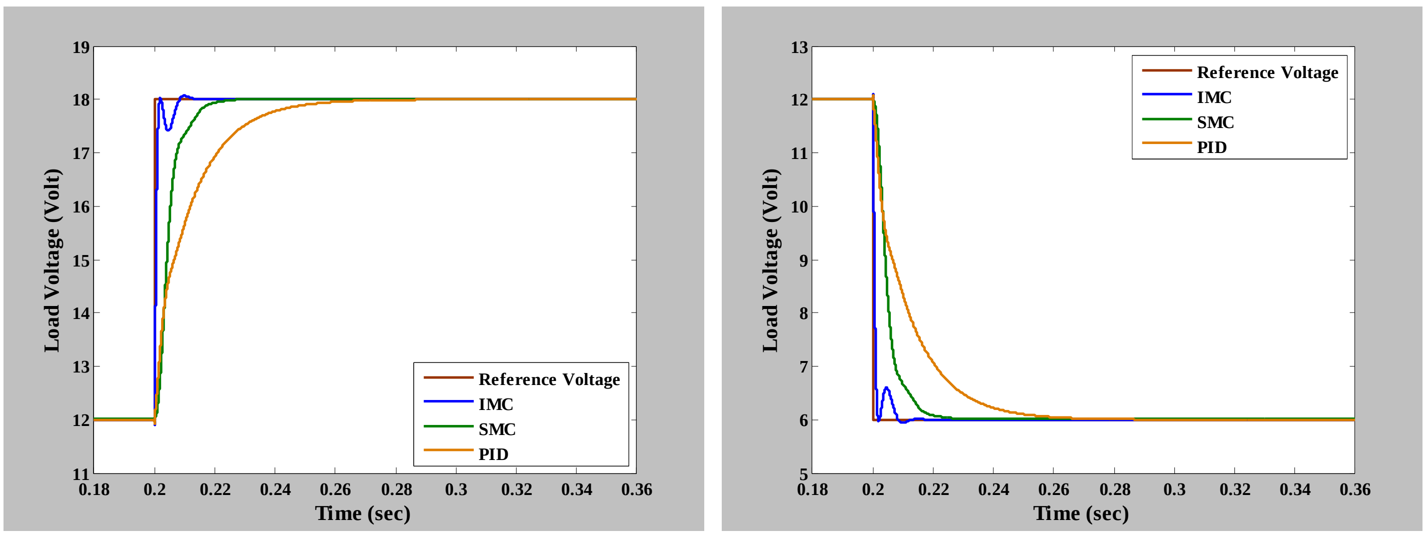
III. RESULTS AND DISCUSSIONS

The closed-loop responses these different controllers like PID, IMC and SMC are examined by using MATLAB/ Simulink platform. The converter's closed-loop performances are performed under load and reference disturbances. The transfer function of the Boost converter is given in Equ.2. The parameters of the Boost converter are given in Table I.

$$T_{P\_Boost}(s)=\frac{-0.005696s^2-0.02559s+4.983\times10^6}{s^2+825.3s+542410} \tag{2}$$

The PID controller is designed in MATLAB SISOTOOL and finally obtained transfer function of PID controller is $T_{c\_PID}(s) = \dfrac{1.915(s+1418.7)(s+417.11)}{s\left(s+1.149\times10^5\right)}$. The IMC and SMC are designed by using details mathematical calculations (**Due to the page limitations the details steps are not included in presented work. But the details calculations will be included after acceptance of this manuscript.**). The transfer function of IMC is $T_{c\_IMC}(s) = \dfrac{281288.6143\left(s^2+580.5s+3.417\times10^5\right)}{\left(s+2.952\times10^4\right)\left(s+2.93\times10^4\right)(s+1020)}$.

A. Output Voltage with Reference Disturbance

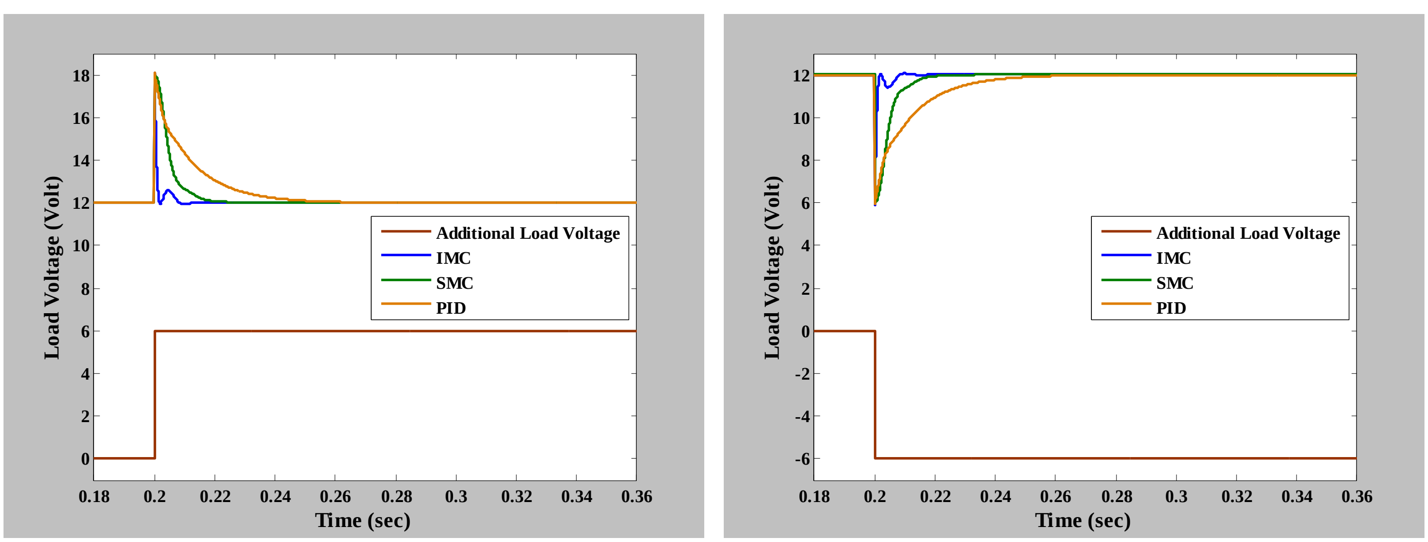


(a) (b)

Fig. 2 (a) & (b) The closed-loop performances of Boost converter with ± 50% reference voltage disturbances.

The Fig.2(a) & Fig.2(b) are showing the tracking performances of load voltage in Boost converter by applying ± 50% additional reference voltage (V_{ref}) disturbances. The Boost converter with IMC is shown the best tracking performance than the SMC or PID controller based Boost converter. The load voltage of IMC based converter has perfectly tracked the reference voltage and settles down quickly maintaining zero steady-state error. So, it may be concluded from simulation results that IMC with Boost converter provides satisfactory tracking performance and exhibits good load regulation in closed-loop.

B. Output Voltage with Load Disturbance



(a) (b)

Fig. 3(a) & (b) The closed-loop performances of Boost converter with ± 50% load voltage disturbances.

The proposed converter's load regulations are checked by adding ± 50% an additional load voltage and closed-loop performances are observed in Fig.3(a) & Fig.3(b) respectively. The Boost converter with the proposed advanced and classical controllers has maintained the load regulation and tries to maintain a fixed load voltage of 12 V. The initial oscillations are observed for immediate changing of load voltages. But finally, it can be observed that the output voltages are maintaining fixed value of 12 V at steady-state. Here the load regulations are welly maintained by all the controllers. But IMC with Boost converter has performed the best closed-loop response (i.e. least settling time & zero overshoot) compare to the other controllers like SMC and PID.

IV. CONCLUSION

In this presented work, the performance study of DC-DC SMPCs with some advanced controllers *like* SMC and IMC has been carried out. Initially the basic theory of SMC and IMC has been presented and mathematical formulations of the converters with the controllers have been developed. The widespread simulation has been performed to compare the performance between classical PID, SMC and IMC controller. The performance analysis of these three controllers with converter are shown that PID controller works satisfactorily in load regulation. Though there is a major parameter tuning issue for PID controller. Even for suitably tuned parameters of PID, converter dynamics are not satisfactory. These limitations may be overcome by IMC and SMC. IMC may appear as a suitable control option for Boost converter and that offers transient response with good steady-state performance. The simulation results are reported here but the practical implementation is going on and that may be future scope of the presented work.

REFERENCES

[1] N. Mohan, and T. M. Undeland, Power electronics: converters, applications, and design, John Wiley & Sons, 2007.

[2] R. W. Erickson, and D. Maksimovic, Fundamentals of power electronics, Springer Science & Business Media, 2007.

[3] K. Ogata, Modern Control Engineering, Pearson Education, India, 2010.

[4] R. C. Dorf, and R. H. Bishop, Modern control systems, Pearson, India, 2011.

[5] W. C. So, C. K. Tse, and Y. S. Lee, "Development of a fuzzy logic controller for DC/DC converters: design, computer simulation, and experimental evaluation," IEEE Transactions on Power Electronics, vol. 11, no. 1, pp. 24-32, 1996.

[6] G. Escobar, R. Ortega, H. Sira-Ramirez, J. P. Vilain, and I. Zein, "An experimental comparison of several nonlinear controllers for power converters," IEEE Control Systems, vol. 19, no. 1, pp. 66-82, 1999.

[7] G. Garcerá, M. Pascual, and E. Figueres, "Robust average current-mode control of multi-module parallel DC-DC PWM converter systems with improved dynamic response," IEEE Transactions on Industrial Electronics, vol. 48, no. 5, pp. 995-1005, 2001.

[8] E. Vidal-Idiarte, L. Martinez-Salamero, H. Valderrama-Blavi, F. Guinjoan, and J. Maixe, "Analysis and design of H^{∞} control of non-minimum phase-switching converters," IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, vol. 50, no. 10, pp. 1316-1323, 2003.

[9] J. Mahdavi, M. R. Nasiri, A. Agah, and A. Emadi, "Application of neural networks and state-space averaging to DC/DC PWM converters in sliding-mode operation," IEEE/ASME Transactions on Mechatronics, vol. 10, no. 1, pp. 60-67, 2005.

[10] C. Y. Chan, "A nonlinear control for DC–DC power converters," IEEE transactions on power electronics, vol. 22, no. 1, pp. 216-222, 2007.

[11] A. Schild, J. Lunze, J. Krupar, and W. Schwarz, "Design of generalized hysteresis controllers for DC–DC switching power converters," IEEE Transactions on Power Electronics, vol. 24, no. 1, pp. 138-146, 2009.

[12] C. Xia, Y. Yan, P. Song, and T. Shi, "Voltage disturbance rejection for matrix converter-based PMSM drive system using internal model control," IEEE Transactions on Industrial Electronics, vol. 59, no. 1, pp. 361-372, 2012.

[13] S. Oucheriah, and L. Guo, "PWM-based adaptive sliding-mode control for boost DC–DC converters," IEEE Transactions on Industrial Electronics, vol. 8, no. 60, pp. 3291-3294, 2013.

[14] K. Tarakanath, S. Patwardhan, and V. Agarwal, " Internal model control of dc-dc boost converter exhibiting non-minimum phase behavior," in IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES-2014), pp. 1-7, December 2014.

[15] A. Ghosh, M. Prakash, S. Pradhan, and S. Banerjee, "A comparison among PID, Sliding Mode and internal model control for a buck converter," in IEEE 40th Annual Conference of the Industrial Electronics Society (IECON-2014), pp. 1001-1006, USA, October 2014.

[16] B. Labbe, B. Allard, and X. Lin-Shi, "Design and stability analysis of a frequency controlled sliding-mode buck converter," IEEE Transactions on Circuits and Systems I: Regular Papers, vol. 61, no. 9, pp. 2761-2770, 2014.

[17] A Ghosh,. and S. Banerjee, "Control of switched-mode Boost converter by using classical and optimized Type controllers," Journal of Control Engineering and Applied Informatics, vol. 17, no. 4, pp. 114-125, 2015.

[18] S. Singh, D. Fulwani, and V. Kumar, "Robust sliding-mode control of dc/dc boost converter feeding a constant power load," IET Power Electronics, vol. 8, no. 7, pp. 1230-1237, 2015.

[19] A. Ghosh, S. Banerjee, M.K. Sarkar, and P. Dutta, "Design and implementation of type-II and type-III controller for DC–DC switched-mode boost converter by using K-factor approach and optimisation techniques," IET Power Electronics, vol. 9, no. 5, pp. 938-950, 2016.

[20] R. Ling, D. Maksimovic, and R. Leyva, "Second-Order Sliding-Mode Controlled Synchronous Buck DC–DC Converter," IEEE Transactions on Power Electronics, vol. 31, no. 3, pp. 2539-2549, 2016.

[21] S. Banerjee, A. Ghosh, and N. Rana, "October. Design and fabrication of closed loop two-phase interleaved boost converter with Type-III controller," 42nd Annual Conference of the IEEE Industrial Electronics Society (IECON 2016), pp. 3331-3336, 2016.

[22] S. Banerjee, A. Ghosh, and N. Rana, "An Improved Interleaved Boost Converter With PSO-Based Optimal Type-III Controller," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 5, no. 1, pp. 323-337, 2017.

[23] N. Rana, A. Ghosh, and S. Banerjee, "Development of an Improved Tristate Buck–Boost Converter With Optimized Type-3 Controller," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 6, no. 1, pp. 400-415, 2018.

[24] N. Rana, M. Kumar, A. Ghosh, S. Banerjee, "A Novel Interleaved Tri-State Boost Converter with Lower Ripple and Improved Dynamic Response," IEEE Transactions on Industrial Electronics. vol. 65, no. 7, pp. 5456-5465, 2018.