NON LINEAR CONTROLLER DESIGN FOR BUCK CONVERTER TO MINIMIZE TRANSIENT DISTURBANCES

Anwar Ali Sahito*, Muhammad AslamUqaili, Abdul SattarLarik, Mukhtiar Ahmed Mahar

Department of Electrical Engineering, Mehran University of Eng. & Tech., Jamshoro

*Contact: anwar.sahito@gmail.com

ABSTRACT: *Switching operations in periodic variable structures of power electronic converters result in generation of harmonics and nonlinearities in the power system. DC-DC converters are widely used due to their fast dynamic response and small size but also generate switching transients and their efficiency is decreased. PI controllers were used to overcome these problems but failed. Sliding mode controller are being used to control dynamics of DC-DC converters because of its simplicity, robustness and capability to handle supply and load variations. This research paper presents the analysis of existing sliding mode controller for buck converter simulation on MATLAB/SIMULINK and results show that transients are still present. A new scheme of SMC is proposed to minimize transient disturbances associated with buck converter.*

Keywords:DC-DC converters, Buck Converter,Sliding mode controller.

INTRODUCTION

Power electronic converters are found in almost every field of modern control systems due to their numerous advantages such as low cost, high efficiency and flexibility in control. DC to DC converters convert DC voltage level and have numerous applications from computer power supplies, Uninterruptable power supplies to control of renewable energy plants of wind mills and solar photovoltaic systems [1-3]. Attractive features of dc-dc topologies include small size, high switching speed, lower conduction loss and fast dynamic response [2,3].

Numerous power electronic applications are benefitting from dc-dc converters having high frequency switching. Size of passive components (capacitor and inductors) used in converter circuit is reduced with increased switching frequency. Switching losses in power electronic convertersincrease as the frequency exceeds the range of 4kHz [3,4].Switching transients in DC-DC converters affects power quality of the converter and power system to which it is connected. Due to vast applications of DC-DC converters, it is one of the interesting field for researchers.

Computer based simulation software are extremely helpful tools in analyzing any model under study. MATLAB Simulink is one of such software equipped with built in models of different power electronic converters. Its excellent analysis libraries can be used to analyze operation of a model, its simple power flow observations to advanced harmonic spectrum analysis and control applications.

This paper illustrates the problems associated with buck converters. Sliding mode controller techniques are discussed and it is proposed that a better performance of buck converter can be obtained using a combination of PI and SMC techniques. SIMULINK is used to observe some different control techniques used for step down buck converter.

BUCK CONVERTER

Buck converteris step down DC-DC converter. Due to its attractive features like compact size and high efficiency, these converters are commonly used in variouscontrol applications. Fig.1 shows basic Buck converter circuit.

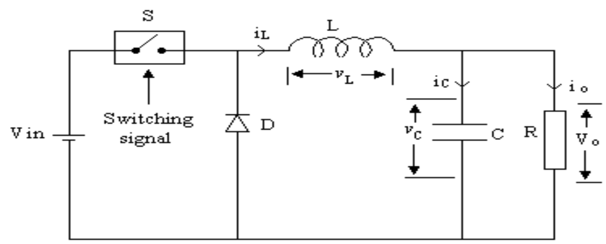


Fig. 1 Buck converter

Based on inductor current a buck converter operation can be categorized in two modes. When inductor current never falls to zero, buck converter is said to be operating in continuous conduction mode (CCM). On the other hand if inductor current falls to zero at some instance, it is called discontinuous conduction mode (DCM). These are shown in Fig. 2 (a and b)

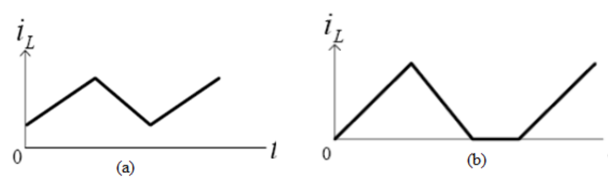


Fig. 2 (a) Continuous conduction (b) Discontinuous conduction, operating modes of Buck converter

To understand the converter operation, all components are assumed ideal andconverter in CCM. The switch is either close or open resulting in two circuit states. Closing the switchwill result in flow of inductor current making the diode reverse biased. When switch is opened, inductor current flows through diode and inductor circuit. Diode in this case is called free wheel diode and it can be said that current freewheels.

This circuit shows that high frequency switching of input current is responsible for voltage level conversion.Oscillations are generated during line and load variations. Harmonics are generated and conduction losses are increased. Therefore efficiency of buck converter is decreased and thus overall efficiency of the system is affected.

Suitable controller for switching operation is required to improve the performance of converter. Several researchers are devoting for development of such controllers to improve performance of buck converters.

CONTROLLERFOR BUCK CONVERTER

In order to control the dynamics of Buck converter, researchers designed different control techniques. Conventional control techniques involved pulse width modulation (PWM) based on averaging techniques. System controlled by such control techniques could only work satisfactorily under specific condition only [4,6].

Linear controllers Proportional (P), Proportional plus integral (PI) and proportional plus integral plus derivative (PID) were used to improve the performance of such converters. Such controllers also failed to give good large signal operating conditions [5].

A proportional only controller causes a steady state error which can be reduced to zero by adding the integral term and using a PI controller.

The PID controller results in a better performance in both steady state and transient state.In PID controller, error, its derivative and integral are linearly combined to form control signal. Controller is tuned to get acceptable performance of the converter. Increasing gain constants for proportional and integral (K_P and K_I) will reduce errors but stability will remain consideration. Stability, damping and error reduction can be achieved by using PID controller [6-8].

Derivative action is highly sensitive to high frequency unwanted distortion available with input. So eliminating a derivative action will cause the controller to be less responsive to such signals. Therefore a PI controller is more suitable in noisy data input and keeps the system more stable in steady state condition. It will also make the system fast to reach the set point.

Raviraj*et al*, compared different controllers for buck converter [6]. He used PI based single-loop voltage-modecontrol and simulation results showed that converter generated high transients with this control technique. He concluded that PI controller can't control transients during line and load variations.

Uranand Milanovicused state controller with PI controller for buck converter [7]. They also stated that ordinary PI controller is slow in response to load variations and large deviations occur then desired output. Simulation results showed an improvement in transient performance and fast response to load variations, but averaging and exact parameters remained problem.

Tsang *et-al*used a control technique where he decomposed buck converter into voltage and current loops [8]. Both loops of the cascaded controller were implemented by PI. Proposed Cascaded controller was used as an add-on to the controller. It shows better results but there was problem of additional cost and complex circuitry. Also transients generated during line and load variations were still unacceptable.

Buti B and Nagy I used constant frequency PWM and PI controller for stability analysis of output voltage of buck converter [9]. Control loops were designed with the help of eigen values and Jacobian matrix. Results showed that buck converter generated transients during load variations.

Demirtas and Gezer simulated buck converter with PI controllers on Labview [10].Study showed that that output voltage can be tuned by changing rate of on-off time by switching signal. Results also show that PI controller used for converter doesn't control the transients during line and load variations.

SLIDING MODE CONTROLLER

Linear controllers could not resolve the control issues in DC-DC converters. Therefore non-linear controllers are being investigated for efficient operation of such converters. Sliding mode controller (SMC) is versatile control technique that provides robustness to variable structure systems (VSS) under parameter variations and external disturbances. As compared to other nonlinear controllers, SMCis easier to implement and shows higher degree of design flexibility.Its approach is systematic and stability is maintained. Variation in supply and load will cause the grains to switch from one point to another between two fixed values. SMC will drive these variations in nonlinear plant's state trajectory on a user chosen surface called switching surface. To control the converter Feedback path will have different gains when plant trajectory is below or above surface. Proper switching rule is then defined by the surface (called sliding surface). Once the process is started, switched control will maintain the plant's state trajectory on the sliding surface for all subsequent time intervals.

Stability, regulation and tracking etc are achieved for variable structure systems by properly designed sliding surface. SMCrequires the knowledge of parameter variation range for its design instead of accurate mathematical models. Irrespective of the order of system to be controlled, SMC will be designed tohave first-order response.Proper sliding surface selection will ensure that even the worst-case dynamics wouldbe handled.

Differentresearchers have used sliding mode controller to control dynamics of buck converter.

Mattavelli*et. al*, proposed a general sliding mode controller for all types of DC/DC converters [11]. Controller showed robustness and simpler application as compared to PI controllers. But controller still shown transients during operation.

Raviraj and T.Sencompared PI, SMC and fuzzy logic controllers for buck converters [6]. They analyzed that PI controller exhibits week response as compared to SMC and fuzzy logic. Two non-linear controllers behaved in a similar manner. Still there were significant transients present.

Muhammad Ahmed *et. al*. proposed sliding mode controller for switched mode power supply [12]. He simulated the model under three conditions; turn on, line and load changes and component variations. Simulation results showed that SMC makes buck converter's performance better and increases the robustness of the system. They also pointed out that load variations severely affect performance of converter. A large change in load may even transfer the operation mode from CCM to DCM. High ripple voltages are generated. Inductor and capacitor values don't affect the converter very much. It was also observed that a large value of capacitor is not required to smooth the output voltage. This is a great advantage of SMC for switched mode power supply.

E. Aroudi*et. al*. proposed SMC technique to be used with a high voltage buck converter containing two switches. He derived some mathematical relations and used numerical analysis techniques to observe the response of the converter. Results showed that controller was working fine under pre defined conditions but any variation in the system parameters or operating conditions generate transients and controller was only suitable for the system studied.

Hoyerby and Andersen proposed SMC scheme with hysteresis, which was useful in properly determining output impedance of the converter [14]. Results also show that accuracy of model is questionable under change in incoming signal, parameter variations and absence of delay due to state-space modeling.

Muhamad, N.D. and Aziz, J.A (2008) modelled sliding mode controller for buck converter on Personal Simulation Program with Integrated Circuit Emphasis(PSpice) [15]. Simulation of the model showed transients. Model is a good tool for study of buck converter with SMC and different parameters can easily be varied to observe their effects.

Huangfu*et. al* compared the performance of a buck converter with PI, conventional SMC and Dynamic SMC [16]. PI controller showed poor performance under load disturbances. Conventional SMC has good performance but had problems with load variations. Dynamic sliding mode controller using two sliding mode controllers showed quite good response to load disturbances.

Naik and Mehta presented a SMC technique with modified sliding function which allows a degree of freedom to determine the dynamic behaviour of overall system [17].This modification allows find the sliding surface with minimum steady state error.

SIMULATION RESULTS

SMC proposed by Muhammad Ahmed's [12]is based on disintegration of controller in two loops; voltage and current. Voltage loop being controlled by PI and current loop was controlled by SMC. Fig. 3 shows SIMULINK model for buck converter with sliding mode controller.

Simulation results are shown in Fig. 4(a,b,c) where 4(a) and 4(b) shows output voltages and 4(c) shows inductor current of the simulated circuits.

RESULTS DISCUSSION

Results of sliding mode controlled buck converter show that transients are still present. Fig 4(a) and (b) show high transients generated during startup for both voltage and current. Overshoot for output voltage is 5V for required 12V. For current overshoot 1.6 mA for rated 0.9 A. These values for overshoot are on higher side. Settling time for both voltage and current is 3 ms which is also high. Fig. 4(b) shows output voltage response load variations. It is clear that transients are generated. As Controller's linear part i.e PI controller for voltage loop is designed on hit and trial basis. Therefore for each supply or load variation, controller needs tuning again on hit and trial. Hence this control technique is only suitable for particular case application and needs adjustments for general purpose usage. Performance of converter is affected under supply and load variations generate harmonics, which decreases the efficiency of converter itself and the system to which it is connected.

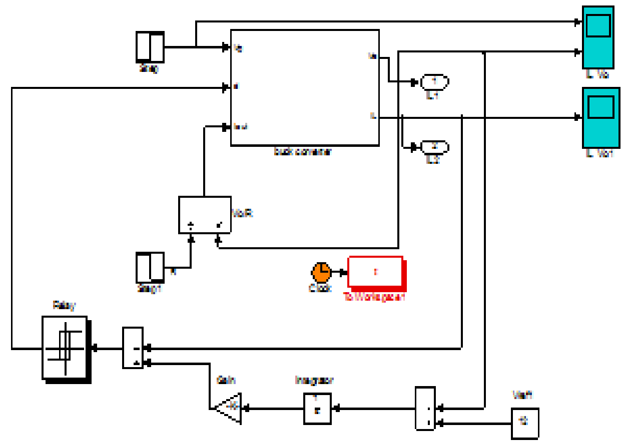
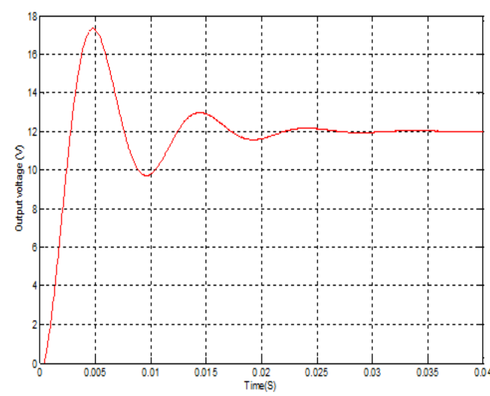
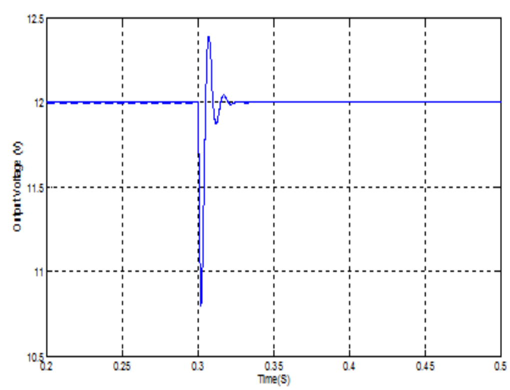


Fig.3SIMULINK model for SMC controlled buck converter



(a)



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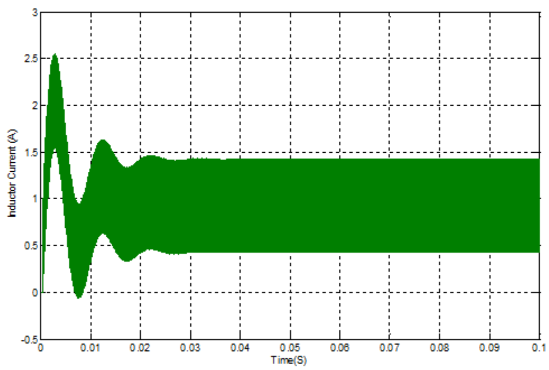

(c)

Fig.4SIMULINK Results for SMC controlled buck converter (a) Voltage, (b) output voltage, (c) Inductor current

Proposed Sliding Mode Controller for Buck Converter

Various efforts made by researchers have evidently improved the performance of SMC for buck converter. Review suggests that a SMC can be used accurately to control the dynamics of buck converter. Fig. 5 shows the proposed scheme for sliding mode controller to be used for buck converter. In this controller scheme mathematical model of voltage loop will be developed which will automatically adjust the gain for PI controller. It will also provide correction signal to non linear current control loop. There is every positive indication thatthis new control technique is likely to improve the transient behavior of buck converter and its efficiency and stability.

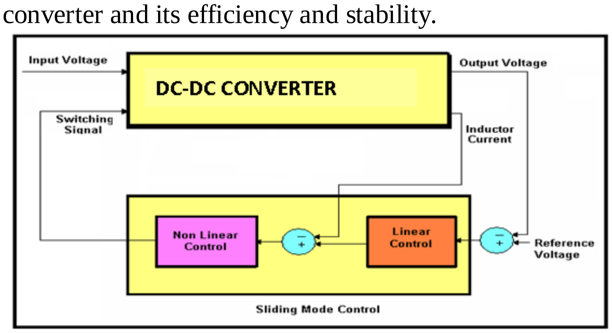

Fig.5Proposed Scheme for SMC controlled buck converter

CONCLUSION

DC-DC converters are variable structure systems and produce switching transients.Transients increase during supply or load variations. Linear controllers especially PI controllers used could not overcome these problems. Being a non-linear controller, SMC handles such behavior in a better way. SMC is preferred because of its robustness and ease of implementation. Existing SMC for buck converter is usually engaged by hit and trial method for linear loop. Therefore, for any supply or load variation, it needs tuning again by hit and trial operation.Proposed SMC will automatically select the optimum values and improve the performance of buck converter even under supply and load variations.

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