A Review of Sliding Mode Control Of DC-DC Converters

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Abstract - *DC–DC converter convert DC voltage signal from high level to low level signal or it can be vise versa depending on the type of converter used in system. DC-DC converters are widely used in a variety of applications, ranging from computer to medical electronic systems, adapters of consumer electronic devices, spacecraft power systems and telecommunication equipments. The paper deals with the of performance of DC-DC buck converter using Sliding Mode Control (SMC). DC/DC converters are widely used in many industrial and electrical systems. DC-DC converters showed a high potential for improving the dynamic performance by applying Sliding Mode Control. This nonlinear control scheme is especially well suited for Variable Structure System (VSS) like DC-DC converters. The main advantage of SMC over common linear control schemes is its high robustness against line, load and parameter variations.*

Key Words: DC–DC converter, Sliding Mode Control (SMC), Buck Power Converter

1. INTRODUCTION

DC-DC converters are widely used power electronics components in industrial area like switching mode power supply (SMPS), personal computer, dc motor drives, etc. The input of the dc-dc converters is unregulated dc voltage obtained by the rectifying line-voltage and a converter converts this input into a regulated dc output voltage at a desired level. Since dc-dc converters have power devices, effect of switching and passive components like inductors and capacitors, they are non-linear systems [1], [2]. Therefore, control methods used to control the converters directly affect the performance of the converter. DC to DC power converters can be used as suitable controlled electronic “starters” for any DC machine There are many types of dc-dc converter which is buck (step down converter), boost (step-up) converter, and buck-boost (step up- step-down) convertor [3], [4]. These converters have received an increasing deal of interest in many areas. This is due to their wide applications like power supplies for personal computers, office equipment, appliance control, telecommunication equipment, DC motor drives, automotive, aircraft, etc.

Different control algorithms are applied to regulate dc-dc converters to achieve a robust output voltage. As dc-dc converters are nonlinear and time variant systems, the application of linear control techniques for the control of these converters are not suit-able. In order to design a linear control system using classical linear control techniques, the small signal model is derived by linearization around a precise operating point from the state space average model [5]. The controllers based on these techniques are simple to implement how-ever, it is difficult to account the variation of system parameters, because of the dependence of small signal model parameters on the converter operating point [6]. Variations of system parameters and large signal transients such as those produced in the start up or against changes in the load, cannot be dealt with these techniques. Multi loop control techniques, such as current mode control, have greatly improved the dynamic behavior, but the control design re-mains difficult especially for higher order converter topologies.

A control technique suitable for dc-dc converters must cope with their intrinsic nonlinearity and wide input volt-age and load variations, ensuring stability in any operating condition while providing fast transient response. Since switching converters constitute a case of variable structure systems, the sliding mode control technique can be a possible option to control this kind of circuits [7]. The sliding mode control is a non linear system, it is derived from variable structure system. It is well known for their stability and robustness against parameters, line and load variation. The flexibility is the design choice. The use of sliding mode control enables to improve and even overcome the deficiency of the control method based on small signal models. In particular, sliding mode control improves the dynamic behavior of the system, and becomes very useful when the system is required to operate in the presence of significant unknown disturbances and plant uncertainties [8].

In order to obtain the desired response, the sliding mode technique changes the structure of the controller in response to the changing state of the system. This is realized by the use of a high speed switching control forcing the trajectory of the system to move to and stay in a predetermined surface which is called sliding surface. The regime of a control system in the sliding surface is called Sliding Mode. In sliding mode a system's response remains insensitive to parameter variations and disturbances [9]. Unlike other robust schemes, which are computationally intensive linear methods, analogue implementations or digital computation of sliding mode is simple. Implementing of SM controller is relatively easy when compare with the other controllers.

2. DC - DC POWER CONVERTERS

Dc-dc power converters are employed in a variety of applications, including power supplies for personal computers, office equipment, spacecraft power systems, laptop computers, and telecommunications equipment, as well as dc motor drives. The input to a dc-dc converter is an unregulated dc voltage Vg. The converter produces a regulated output voltage V, having a magnitude (and possibly polarity) that differs from Vg.

2.1 Buck Converter

Buck converter is a step down DC-DC converter. Due to its attractive features like compact size and high efficiency, these converters are commonly used in various control applications [10]. Fig.1 shows basic Buck converter circuit.

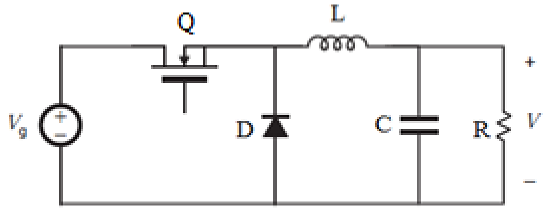

Fig -1: Basic Buck Converter Circuit

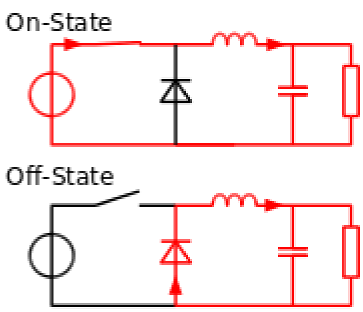

Fig -2: The two circuit configurations of a buck converter: On-state and Off-state.

The basic operation of the buck converter has the current in an inductor controlled by two switches (usually a transistor and a diode). In the idealized converter, all the components are considered to be perfect. Specifically, the switch and the diode have zero voltage drop when on and zero current flow when off and the inductor has zero series resistance. Further, it is assumed that the input and output voltages do not change over the course of a cycle (this would imply the output capacitance as being infinite).

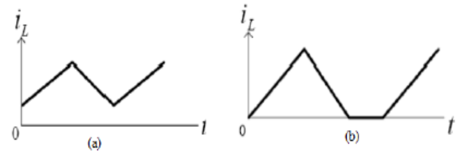

Fig -3: (a) Continuous conduction (b) Discontinuous conduction, operating modes of Buck converter

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.3(a and b).

2.2 Boost Converter

Boost converter is a step–up converter. The boost converter will produce an output voltage ranging from the same voltage as the input, to a level much higher than the input i.e., it is a voltage elevator. Boost converters are used in battery powered devices, where the circuit requires a higher operating voltage than the battery can supply, e.g. laptops, mobile phones, camera flashes & battery powered vehicles. The function of boost converter is like during ON time of switch inductance is charged with energy & during the OFF time of the switch this energy is transferred from the inductor through the diode to the output capacitor. Control of this type of converter is more difficult than buck converter, where output voltage is smaller than input voltage. Control of boost converter is difficult due to their non minimum phase structure, since control input appears in voltage as well as current equations [11].

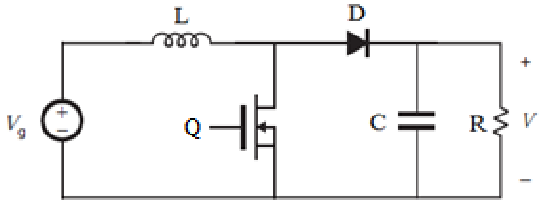

Fig -4: Boost Converter Circuit

The boost converter is shown in Fig. 4. When the control signal Q is 1, the circuit is shown in Fig. 5(a). The inductor *L* is being charged by the input voltage *Vg*, and the capacitor *C* is being discharged through the resistor *R*. When Q is 0, the circuit is shown in Fig. 5(b). *Vg* and *L* charge *C*. The output (load) voltage is *v* and *i* be the inductor current.

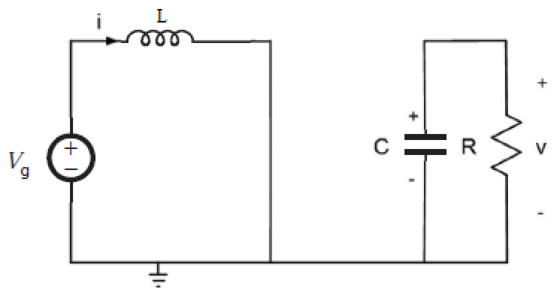

Fig -5: (a). Boost converter when Q is ON

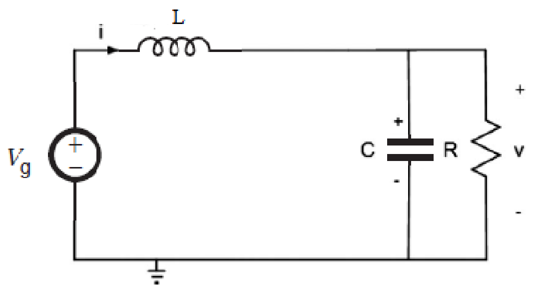

Fig -5: (b). Boost converter when Q is OFF.

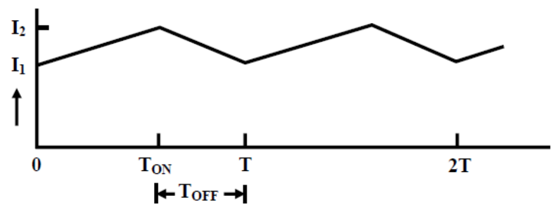

Fig -6: Waveforms of source current (*i*)

In this case, the output voltage is higher than the input voltage, as contrasted with the previous case of buck converter (dc-dc). So, this is called boost converter (dc-dc), when a self-commutated device is used as a switch. Instead, if thyristor is used in its place, this is termed as step-up chopper. The variation (range) of the output voltage can be easily computed.

2.3 Buck-Boost Converter

Buck-boost converters are a typical type of power conditioning devices due to its simple structure and practical functionality of dropping or lifting the output voltage with respect to an input voltage. Buck-boost converter provides an output voltage which can be higher or lower than the input voltage. The output voltage polarity is opposite to that of the input voltage. Buck-boost converter can be obtained by the cascade connection of the two basic converters which are the step down converter and step up converter. These two converters can be combined into the single buck- input provides energy to the inductor and the diode is reverse biased.

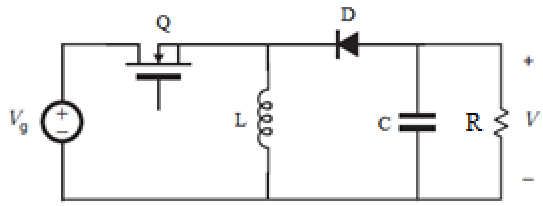

Fig -7: Buck-boost Converter Circuit

The buck-boost converter is shown in Fig. 7. It consists of an input voltage source *Vg*, a transistor switch Q, a diode *D*, a capacitor *C*, an inductor *L* and a load resistor *R* [12]. The inductor current is *i*. The output voltage across the resistor is *v*. The absolute value of *v* can be greater or less than *Vg*. *v* is opposite to *Vg* in polarity. When *Q* is on, the circuit is shown in Fig. 8(a). The voltage source *Vg* supplies energy to the inductor *L* and the capacitor *C* supplies energy to the load resistor *R*. When *Q* is off, the circuit is shown in Fig. 8(b). The connection of the diode may be noted, as compared with its connection in a boost converter. The inductor, L is connected in parallel after the switch and before the diode. The load is of the same type as given earlier. A capacitor, C is connected in parallel with the load. The polarity of the output voltage is opposite to that of input voltage here.

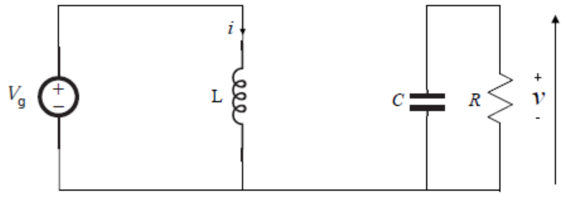

Fig. 8: (a). Buck-boost converter when Q is ON

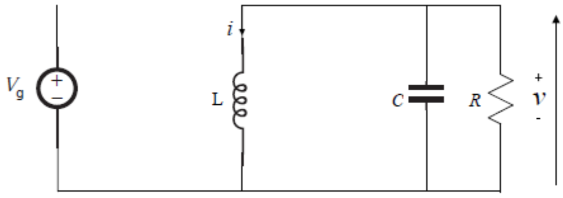

Fig. 8: (b). Buck-boost converter when Q is OFF

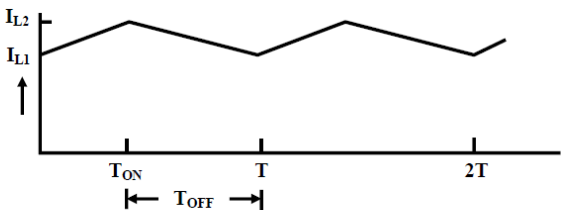

Fig. 9: Inductor current (i) waveform

The path of the current is through L, parallel combination of load & C, and diode D, during the time interval, T_{OFF}. The output voltage remains nearly constant, as the capacitor is connected across the load.

3. SLIDING MODE CONTROL

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 [13-17]. As compared to other nonlinear controllers, SMC is 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. SMC requires 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 to have first-order response. Proper sliding surface selection will ensure that even the worst-case dynamics would be handled. Mattavelli*et. al*, proposed a general sliding mode controller for all types of DC/DC converters [18].

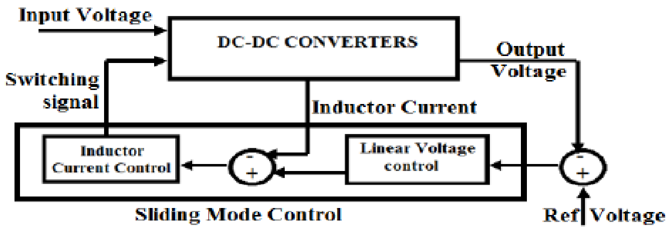

Fig.10: Block Diagram of Sliding Mode Control

The basic principle behind the SMC controlled system is to drive the converter to the steady surface called the sliding surface and maintain the stability of the system thus giving the regulated output voltage for any variations in the load or switching frequency [19].

4. CONCLUSION

A review of sliding mode control of DC-DC converter has been presented. SMC provides several advantages over other control methods: Robustness, stability for even very large line and load variations, good dynamic response and simple implementation. The study shows that Buck converters are most widely used dc–dc converters in the world because no other topology is as simple. Their applications range from low-power regulators to very high power step-down converters, which are characterized by a low number of components, low control complexity, and no insulation.

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