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Transient Performance Improvement of Boost Converter using Sliding Mode Controller

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Abstract: Suitable controller design for Boost converter is important to increase its performance in various applications like renewable energy integration and control circuitries. Linear controller are proved to be inefficient under varying operating conditions. Sliding Mode Controller (SMC) is a nonlinear controller offering advantages of robustness, fast dynamic response and ease of implementation.

In this research work, SMC for Boost converter is proposed and analyzed using MATLAB® SIMULINK® as simulation platform. State space modelling technique is used for Boost converter. Proposed SMC comprises of two loops; voltage and current, controlled by Proportional Integral (PI) and Hysteresis respectively. Simulation of Boost converter with proposed controller shows good response in terms of less overshoot and settling time for initial transient, supply, load and reference variations.

Keywords: Boost converter; Sliding mode controller; Transient response; Load variations.

1. INTRODUCTION

Use of power electronic converters have drastically increased with the development of power semiconductor technology and increasing need of high efficiency, low cost and small size power appliances. Conversion from one DC voltage level to another is performed using DC-DCconverters. DC-DC converters have numerous applications in power system from control of renewable energy resources to small switched mode power supply (Mahar, *et. al.* 2011). Quick dynamic response, fast switching speed, minimum conduction loss and nominal size are identified as advantages of DC-DC topologies (Larik, *et. al.* 2008). High switching frequency is reason behind small size and high efficiency of such converters. Smaller size reduce required size of inductors and capacitors used in converter circuit. As switching frequency crosses the limit of 4 kHz, the switching losses in converters increase (Blaabjerg, *et. al.* 2005). Switching transients in DC-DC converters affect its power quality and its integrated system. DC-DC converters generate transients and harmonics during their operation due to inherent switching action. In order to get maximum benefits from these converters, suitable control technique is required.

Most of the studies have been made by the researchers in terms of design various control techniques for the dynamics of boost converter. To improve the efficiency of boost converter PI controller was used but the proposed controller has unaccepted transients during load variations (Kumar, *et. al.* 2014). For boost converter, the Fractional Order PID was proposed, this technique is based on multi objective optimization evolutionary methods.

Proportional Integral Derivative PID controller was used to control dynamics of the boost converter by (Bhowate and Deogade, 2015). They suggested that PID tuning is quite difficult using graphs and mathematical analysis. They summarized PID tuning by standard methods such as Ziegler Nicholas step response method, Chien-Hrones-Reswick method and loop shaping method. They compared the results obtained from the above described method and formed its results based on dynamic load changing and dynamic input voltage change and conclude that the Loop shaping method is easy to implement as compared to other tuning techniques. Their proposed controller showed high overshoot and settling time for line.

(Tehrani, *et. al.* 2010) proposed fractional control control algorithm showing good start up performance on desired dynamic response. The obtained results show that fractional controllers are better than integer controllers. The problems of simulating fractional Order PID is order in correlation with conventional PID controllers.

(Mulley and Nagarale, 2013) designed DC-DC boost converter operating in continuous conduction mode controlled with pulse width modulation based sliding mode controller. The efficiency of sliding mode controller is compared with PID controller and PI controller and concluded that designed controller give better voltage regulation which is appropriate for

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DC-DC boost converter. Proposed controller showed high overshoot for line variations.

A model predictive control (MPC) technique for DC-DC Boost converters is proposed which directly controls the output voltage with its reference devoid of an underlying current control loop by (Karamanakos, *et. al.* 2014), which perform fast dynamics during transient.

Stability analysis of boost converter is discussed by current control mode and found that by properly designing the control as well as compensation loop, the stability of the current mode regulator is obtained (Yao, 2012). When Current Mode Control is applied in the topology of converters functioning in Continuous Conduction Mode, the current feedback loop come to be changeable if the duty cycle exceeds 0.5. That instability is known as Sub harmonic oscillation.

Dynamic modeling and the performance of current mode control of boost converter with slope compensation is introduced by (Song and Abedi, 2012). They formed the two loops, an outer voltage and an inner current loop and studied that the inner loop is much faster that the outer voltage loop. They also concluded that the boost converter is controlled better with voltage control causing reduced current ripples. If duty cycle exceeds 50%, a disturbance leads to maximum changing from the normal operating points. Design of controlled voltage bus for a PV source utilized in hybrid DC distribution system infrastructure is proposed by (Amin, *et. al.* 2010). They found that PI control scheme for the boost converter is successful in controlling PV power to provide the DC distribution system. They obtained their results by applying line as well as load variation and analyzed that the output voltage is stable despite of changes in line and load. But their proposed controller gives high overshoot and settling time for line and load variations.

Digital voltage-mode controller for a zero-voltage turn on high gain boost converteris designed by (Veerachary and Sekhar, 2011). Circuit theory principles are used for analyzing the steady-state performance of the converters of the converter. Given converter operates with five modes of operation in a single switching cycle and a result is zero voltage transition.

A method to take advantage of voltage mode hysteretic control in DC-DC step up converters by controlling the output voltage and inductor current by distinct loops is proposed by (Keskar and Rincon-Mora, 2004). The circuit presents better voltage regulation and transient response. The efficiency was slightly degraded at high loads due to higher IR loss related with the inductor current.

Any model under investigation can be studied through the helpful technique of simulation software such as MATLAB® Simulink®. Through MATLAB the operation of a model can be investigated because of its superb analysis libraries. Control schemes are easily implemented and analyzed using state space averaging techniques and circuit modelling.

Section 2 of the paper elaborates working of Boost converter. Equations governing its operation are developed and discussed. Section 3 gives description of the sliding mode controller. Controller model is developed for Boost converter. Simulation results and discussions for the SMC controlled Boost converter are given in section 4. Initial transient, steady state and effects of supply and load variations are analyzed in this sections. Paper is finally concluded in section 5.

2. BOOST CONVERTER

Boost converter is step up DC regulator. **(Fig. 1)** shows circuit diagram of boost converter where power electronic switch (S) is controlled through high frequency. Its components contains diode D, semiconductor switch, capacitor C and inductor L. The output voltage of boost converter is controlled by controlling the duty cycle of MOSFET. The boost converter increases the magnitude of output voltage by using energy storing principle in the inductor and capacitor.

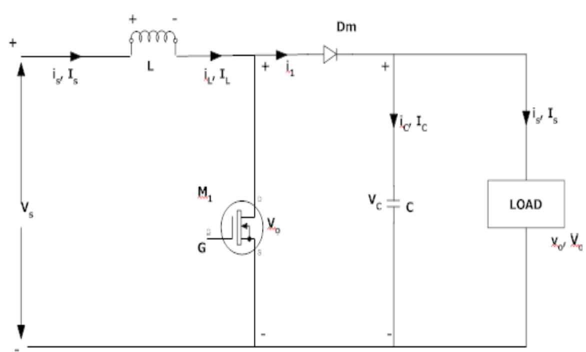

Fig. 1: Boost converter circuit

When switch is ON, current flows through inductor which stores energy by generating field across it. Polarity on the left side of the inductor becomes positive. Capacitor (C) smoothens output voltage to have a very small ripple. Applying Kirchhoff's current and voltage laws yields equation (1)

$$\begin{bmatrix} i_L' \\ v_o' \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ v_0 \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in} \qquad (1)$$

When the switch is OFF current is reduced by high impedance. Initially, the magnetic field created will be destroyed to maintain the current towards the load and as a result reverse polarity is obtained. Two sources will be in series causing a higher voltage to charge the capacitor through the diode D. Eq. (2) presents relations for voltage and inductor current during switch OFF position.

$$\begin{bmatrix} i'_L \\ v'_o \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ v_0 \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in} \quad (2)$$

By performing two actions on equation (1) and (2), i-e multiplying R.H.S of (1) with D and (2) with (1-D) and then by adding them, the resultant equation is followed in equation (3).

$$\begin{bmatrix} i'_L \\ v'_o \end{bmatrix} = \begin{bmatrix} 0 & \frac{D-1}{L} \\ \frac{1-D}{C} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ v_0 \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in} \quad (3)$$

3. SLIDING MODE CONTROLLER

The control problems associated with DC-DC converters could not be settled through linear controllers, hence for smooth and proper functioning of these converters the nonlinear controllers are being used. Comparatively SMC is simple and easy to implement and moreover displays greater degree of flexibility. Furthermore by the use of SMC the stability is controlled.

Sliding surface is user chosen function in SMC. Controller will drive system trajectories to desired sliding surface through high speed switching control law. Thereafter system trajectories will be maintained on sliding surface under subsequent time intervals. Instead of controlling system states, SMC is known to control system trajectories (Jamal and Ammar, 2007). Robustness against parameter is major advantage of SMC. It shows good dynamic response against large input voltage and load variations. In SMC, first equilibrium point is chosen by defining a suitable sliding surface and system trajectories are forced to lie on the sliding surface (Vazquez, *et. al.* 2003).

SMC is easy to implement just like switching between two states (OFF or ON). It does not require any precise mathematical modelling for controller. Discrete control law ensures that sliding mode is reachable in finite time which is better than asymptotic behavior. Control law selection ensures that once sliding mode is achieved, it remains in the control trajectory. Based upon sign of the distance of state from sliding surface, control law shifts from old state to new state. Therefore SMC always pushes the system to sliding surface. So the switching function is like a topographic map with a contour of constant height along which trajectories are forced to move (Larik, *et. al.* 2009).

Stability under load, line and parameter variations are its advantages therefore SMC is used in different nonlinear system applications like furnace control, electric vehicles, nuclear power plants, motor drives, inverters and DC-DC converters (Khandekar and Patre, 2015).

4. RESULTS AND DISCUSSIONS

Table 1 gives parameters of the boost converter to be analyzed in this paper. It is used to step up 10V to 20V.Proposed SMC for boost converter is consists of two parts; current control implemented through hysteresis and voltage control implemented by PI controller. Linear control is implemented through integral with Kp = 10 and Ki =2000.Switching point for hysteresis control is selected as 0.25 and -0.25. (**Fig. 2**) shows complete simulation diagram of the boost converter with proposed SMC.

Table 1. Parameters of Boost Converter

Parameter	Value
Supply Voltage(Vin)	10V
Output Voltage(Vo)	20V
Inductor(L)	250 μH
Capacitor(C)	10 μF
Load Resistance(R)	8 Ω

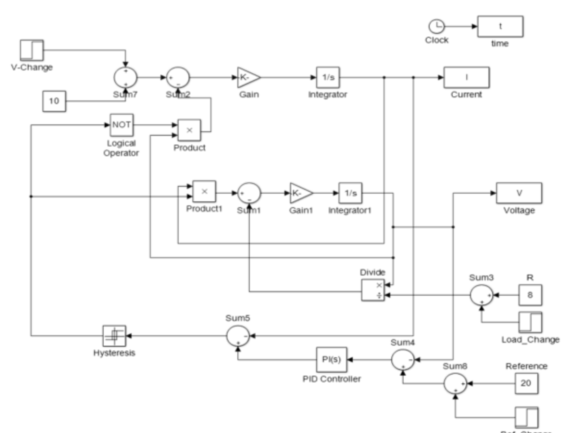

Fig. 2: Simulation diagram of Boost converter with proposed SMC

Initial startup of output voltage of the SMC controlled boost converter is shown in **(Fig. 3)** which has a settling time of 0.2 ms and shows no overshoot. Similarly no overshot and 0.2 ms settling time is observed for inductor current shown in **(Fig. 4). (Fig. 5)** shows steady state ripple of inductor current, which is 1A from 0.7A to 1.7A.

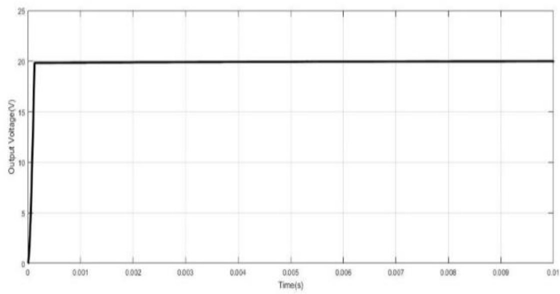

Fig. 3: Initial transient response of output voltage of boost converter with proposed SMC

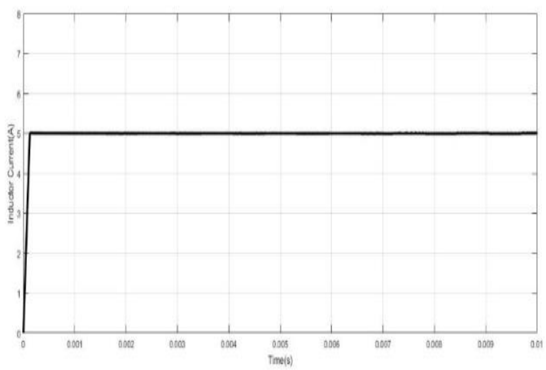

Fig. 4: Initial transient response of Inductor current of boost converter with proposed SMC

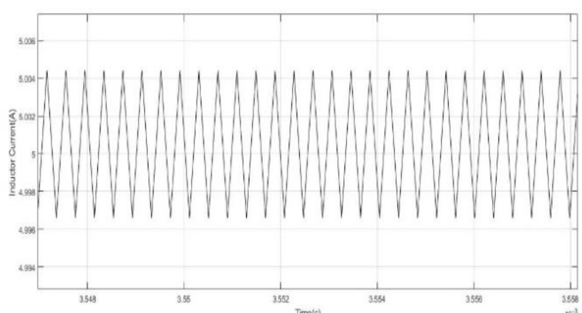

Fig. 5: Inductor current ripple of boost converter with proposed SMC

A step change in supply voltage is applied to check response against supply variation. Input voltage is decreased from 10V to 6V (40% reduction). **(Fig. 6)** shows output voltage waveform in response to applied line variation. Undershoot of 0.1V is observed and settling time of 8ms. To observe the performance of the proposed controller against load variations, a step change in load resistance is applied to increase the load from 8 Ω to 10 Ω (20%). **(Fig. 7)** shows output voltage response for load variation. An undershoot of 0.1V and settling time of 8ms is observed. **(Fig. 8)** shows inductor current response for line variation. Overshoot of 0.8A with settling time of 8ms is observed.

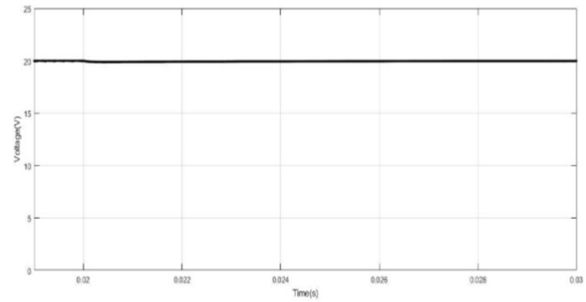

Fig. 6: Voltage response of boost converter with proposed SMC when input voltage is changed from 10V to 6V.

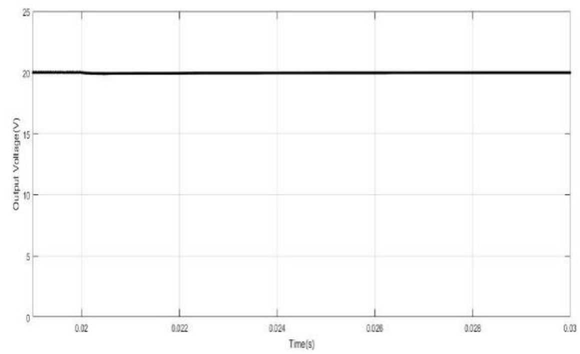

Fig. 7: Voltage response of boost converter with proposed SMC when load is changed from 8 Ωto 10Ω.

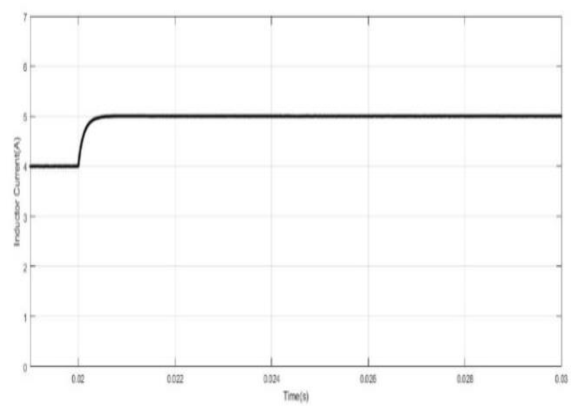

Fig. 8: Inductor current response of boost converter with proposed SMC when load is changed from 8 Ω to 10 Ω

5. CONCLUSION

Linear PI controllers failed to satisfactorily control the dynamics of boost converter under line and load variations. In this research paper SMC is proposed to control the dynamics of boost converter. Proposed SMC has two parts; linear part implemented by PI controller and nonlinear part implemented by hysteresis. Simulation of boost converter with proposed SMC show small overshoot in voltage and inductor current for initial transient and line variations. For 20% increase in load, undershoot in output voltage is 0.1V and overshot in inductor current is 0.8 A. Settling time for all the cases is 8ms. Simulation results confirm effectiveness of proposed SMC for boost converter.

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