Advantages of Sliding Mode Control in dc-dc Converter

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Abstract: This study has been undertaken to reveal the advantages of sliding mode control of the dc-dc converter in different situations. As renewable energy importance increased all over the world, the control methods of dc-dc converters become important for best results. An analysis of the through literature review indicates that the sliding mode control method as compared to the slower conventional methods showing better results in stability of whole system. This nonlinear control scheme has been well suited for variable structure system like dc-dc converter.

Index Terms: **Boost converter, sliding mode control (SMC), nonlinear controller, pulse width modulation (PWM).**

I. INTRODUCTION

dc-dc converters are applied in industries like hybrid electric vehicles, regenerative braking of dc motors, trolley cars, microgrid, uninterruptible power supply (UPS), etc. It converts the unregulated input dc voltage into regulated dc output voltage at a desired level. Controlling the dc-dc converter is a difficult task for power electronics engineers and control engineering engineers. Because of simplicity and less cost, several industries use linear controllers like PI or PID control for regulating dc-dc converters. For parameters variations like huge variations in load or input voltage these controllers are not robust. So linear control methods are not suitable for dc-dc converters. dc-dc converter is good example of non-linear system displaying nonminimum phase characteristics while examined to variations of the small signal. Hence nonlinear controllers are appropriate for controlling dc-dc converters. A stable transient response can be obtained under the various conditions by using these nonlinear controllers.

The author through this paper have tried to review the advantages of sliding mode control technique in dc-dc converter connected with different systems. There are four sections in this paper, section I introduces about dc-dc converter. Section II deals with the basic idea of sliding mode control. Section III summarizes the advantage of the nonlinear control technique in literature. Section IV concludes the article along with future scope of sliding mode control in dc-dc converter.

II. SLIDING MODE CONTROL

Sliding Mode Control is a variable structure control method that alters the dynamics of the system by application of a discontinuous control signal. This signal forces the system to "slide" along a cross-section of the system's normal behavior. The motion of the system which slides beside these boundaries is called sliding mode and the geometrical locus of the boundary is called sliding surface. The sliding control method is a variable structure control method because its state feedback control law is not a continuous function of time, it can switch from one continuous structure to another based on the ongoing position in the state space. Multiple control structures are designed so that trajectories always move toward an adjoining region with a different control structure. The ultimate trajectory will not exist entirely within one control structure and it will slide along the boundaries of the control structures. The sliding mode control provides an approach to design a controller for a system so that the controlled system is dynamically stable and insensitive to parameter variations and external load disturbances. The approach is realized by the use of a high speed switching control law which forces the system to slide along the sliding surface. Sliding mode control can be satisfied with the help of three conditions hitting, existence and stability condition. There is a control directed towards the switching surface before the system reaches the switching surface which is called reaching mode.

III. SMC IN VARIOUS SITUATIONS

Siew Chong Tan et.al. in [1] describes the issues related to analog implementation of PWM based sliding mode (SM) controller of boost converter. The author illustrated a method of modeling the system and the transmission of SM control equations for the PWM implementation. Control technique realized with analog circuit and static and dynamic performance evaluated. In steady-state performance, maximum line-regulation error occurs at minimum load. For analysis of dynamic behavior, it is compared with PWM peak current mode controller. Peak current-mode controller is designed under a linearized small signal model which is optimal to specific operating conditions so response becomes more oscillatory at higher input voltages. On the other hand in PWM based SM voltage controller, the dynamic behavior of the output voltage ripple is critically damped for all operating input and load conditions. Moreover, the transient setting time becomes constant. The authors addressed the strength of the SM controller in terms of robustness in the dynamic behavior under different operating conditions and uncertainties. In case of a discontinuous mode of converter, SM control is applicable only for light load operations.

Yan Ping Jiao in [2] proposed a system converting solar energy to electricity and connecting to utility network. The system includes 6kW/186 V dc solar-panel, dc-dc converter, dc-ac inverter, and output power at least 5kW to the utility system. The author proposes an improved SMC by setting an initial value of sliding function to be zero at startup because conventional SMC gives high current overshoot during start-u. An integral term is also introduced to the sliding surface function to suppress the steady-state error. The improved method can make the response faster and less overshoot when there is a change in input voltage or load. Author suggests that the control method can also be applied to other topologies of the converter.

Alberto Cavallo in [3] presented different sliding mode controls for buck, boost and bidirectional converter with the objective of direct voltage feedback. The author adopted an approach based on the mathematical tools of first and second-order sliding mode output control. Both the nonlinearity of the system and the switching characteristic of the control action can be solved with the use of a variable structure signal strategy. In simple (unidirectional) converters like buck converter and boost converter, there is a limitation of sliding strategy. This limitation can overcome when a bidirectional architecture is considered, that allows both buck and boost output voltage feedback. Simulations of the system provide effectiveness and the robustness of the proposed approach. The proposed control strategy is novel in terms of disturbance rejection and fast-tracking of output reference.

K. Kanimozhi in [4] proposed a sliding mode controller for fixed frequency PWM based boost converter. The boost converter is modeled with the help of dynamic equations describing the converter. The performance of the controller is compared with a conventional PID (proportional integral derivative) controller. When compared with PID control method, Sliding mode controller has the maximum overshoot voltage but the voltage drop and settling time is more in PID controller. The converter system acquires the robustness feature of achieving a stable steady-state response and fast transient response under varying operating points. The author addressed that the PWM based sliding mode controller gives acceptable performance than the PID controller having lowest deviation from reference voltage under input voltages changes. Using the sliding mode controller, the nonlinearity and instability of power converters can be improved which is applicable in many engineering applications.

Khalid A. Abbas et. al in [5] presented sliding mode in buck-boost converter. The model of buck-boost converter has been tested for a sudden step-change in the resistive load and dc supply voltage for both buck and boost operation. Author showed that the step-down and the step-up conversion process of the converter is feasible using sliding mode which maintains the robustness of the system. Only disadvantage in the modeling of system, is the use of current sensor in control part of the system.

Sachin C. S. et. al in [6] compared PI control and sliding mode control of boost converter. The sliding mode control is robust to load variations and provide consistent performance. Voltage drop and settling time of SM controller is less than PI controller. Therefore, SM controller is suitable for common dc-dc boost converter applications.

Satyajit Hemant Chincholkar et.al.in [7] presents an improved pulse width modulation based sliding-mode (SM) controller for the regulation of a 2-stage dc-dc cascade boost converter. The drawback of the existing SM controller is that its use in the regulation of the high-order dc-dc converter results in a trade-off between the overshoot and speed of the transient output response. In order to overcome this problem, the author designed a sliding surface of the SM controller such that the integral action in the resulting equivalent control signal. This method improves the closed loop output voltage response. The author suggests that this method is also applicable in higher order dc-dc converters.

Aditi Kumbhojkar and Nitinkumar in [8] have used Sliding Mode Controller which is cascaded with PI voltage controller for dc to dc boost converter. To compare the performance of the PI Controller and Sliding Mode Controller for DC to DC boost converter author used PI-PI cascade control and PI-SMC cascade control. The author used voltage controller as PI controller and the current controller as sliding Mode Controller. The purpose of this controller is to merely reformulate the voltage reference problem to current reference problem. Sliding control method used here is terminal sliding mode controller. Author showed SMC improves the dynamic response of the controller which is often necessary for high precision applications. The system with sliding mode control exhibit no overshoot, less response time, less steady-state error, less tracking time, less settling time.

Singh et.al. in [9] presented a robust PWM based sliding mode controller for a dc-dc boost converter feeding the CPL (constant power load) in a typical dc microgrid. CPL requires constant voltage for the operation but due to oscillations in the input bus voltage, there is voltage collapse some times. The author explains a non-linear surface which gives constant power to be delivered to the load. The control technique applied here is sliding mode control. The author uses OPAL-RT real-time digital simulator for the implementation of the controller. The controller is capable of handling negative impedance instabilities under the worst case when the total load connected to the system is of CPL nature.

Charaabi Asma et.al. in [10] discussed the methods to provide simplicity in a cascade sliding mode control SMC-PI system by using first-order single loop control and cascade classical PI control. In cascade connection the inner current and the outer voltage controllers are designed, in fact the control aim is to follow a constant reference voltage under the presence of disturbances and uncertainties. The result shows that the SMC-PI allows the output voltage to converge rapidly into the desired value with a settling time more than PI, for PI controller the output voltage catch slowly the reference value with a settling time less than SMC, because in the SMC controller the settling time presented a static error voltage and a current oscillation. The cascade sliding mode control SMC-PI system has robust characteristics and a fast transient response under load resistance and input voltage variations.

Blanca et. al. in [11] reported a method of tracking the problem of controlling boost converter by sliding mode control supplying constant power load. The author proposed a linear switching surface to overcome the intrinsically unstable behavior of the converter in both on and off states which reduce the inrush current and regulate the output voltage.

Irfan and Ersagun in [12] proposed as a new approach for the voltage tracking control of the dc-dc boost converter affected by disturbances, such as the variations in the input voltage and the load resistance. A terminal sliding mode control (TSMC) is designed which enhances the robustness of the conventional sliding mode control (SMC). The proposed controller can track the output voltage reference with short settling time and small overshoot.

Rong-Jong Wai in [13] designed a total sliding-mode control (TSMC) scheme for the voltage tracking control of a conventional dc-dc boost converter. This control strategy depends on Lyapunov stability theorem such that the stable tracking performance can be ensured under the occurrence of system uncertainties. The best feature of this control scheme is that the controlled system has a total sliding motion without a reaching phase. According to the author, the proposed TSMC scheme has over 98.4% voltage tracking improvements in numerical simulations in compare to the conventional sliding mode control. Comparing to the PIC strategy, the TSMC system is implemented without manual retuning parameters before being transferred to the process under different operation conditions, and it has superior and robust control performance. In comparison with the CSMC scheme, the TSMC system is relatively insensitive to system uncertainties because of the total sliding motion during the whole control period and has smaller chattering control efforts due to the help of an auxiliary term in the TSMC design.

Navid and Sepehr in [14] proposed a dual surface sliding mode controller to increase robustness and speed of boost converter. In addition, a filtered mapping pulse width modulation technique is used to attenuate the chattering problem caused by finite frequency switching. Ripple domain search (RDS), a precise maximum power point tracking (MPPT) algorithm, has been applied to find the maximum power point (MPP) in photovoltaic. By combining the fast controller and the RDS algorithm, a fast and robust MPPT technique has obtained, which is simple to implement, eliminates the need for initial parameter tuning and is free from oscillations. On comparing this system with a system applied with the P&O algorithm, the given method harvests a 6% higher power than P & O and constant voltage. The proposed technique has advantages like fastness, robustness, and accuracy. This method is free from oscillations and eliminates the need for initial parameter tuning.

Dan Shen et. al. in [15] proposed a standalone distributed photovoltaic system which includes two solar power sources, battery storage, and a resistive load. Maximum power point tracking (MPPT) control strategy has introduced to maximize the simultaneous energy harvesting from both renewable sources. Power converters interfacing the source and common DC bus has been controlled using a PI-sliding mode controller. Author used two sliding mode surfaces and control variables are obtained through a mathematical modeling of circuit. Sliding mode control gives accurate results in the dc microgrid.

Mohamed B. Debbat in [16] designed a robust control for two-level boost dc-dc converter operating in continuous conduction mode (CCM). The author showed that SMC is very effective in rejecting the change effects of input voltage and SMC is faster and robust than the cascade PI controller. The experimental results also show an overall behavior of SMC better than PI.

Momeneh et.al.in [17] explained a dc-dc boost resonant-inductor converter with a stable operation using a sliding-mode control. The author showed that the control scheme provides zero-current switching, fast transient response, and soft converter start-up. Thus, the resonant-inductor converter with the sliding mode control improves the performance of the conventional boost converter.

Mahdi Salimi in [18] explained a new proportional-integral type hyper plane sliding mode controller for output voltage control of the dc-dc buck-boost converter. This is designed for both continuous and discontinuous conduction modes of operation. In addition, it is capable of canceling the non-minimum phase nature effect of the converter so that the designed controller does not need to know the inductor reference current. The coefficients of the controller have been designed so that the steady-state error of the converter asymptotically converges to zero. The controller is designed based on fixed-frequency. The coefficients of the proposed controller have been obtained based on preserving the converter system stability and its robustness against parameter uncertainties, load disturbances and with subject to variations of the converter input voltage. These coefficients have been obtained so that the non-minimum phase nature effect of the mentioned converter has been canceled. Control method shows that there is no need to know the inductor reference current. Two cascaded conventional PI controllers or a PI controller in cascade with a first-order SMC can also be used for output voltage control of the dc-dc buck/boost converter. However, these control schemes are weak with subject to converter parameters variations and load disturbances as mentioned above. Although two cascaded first-order SMC can solve the non-minimum phase problem, it is difficult to implement in practice.

Sandeep Tyagi in [19] proposed a controller using a sliding mode technique with modified values of parameters and beta factor for precise values using feedback, closed loop system. The input source is a dc source voltage. The control parameter is voltage. A unique method is provided to control the converters duty-cycle and increase system efficiency for each parameter. The analysis is performed on three different conditions of the input voltage. The output remains nearly same for different loads. The settling time for SM controller remains nearly same, which is about 3.4 milliseconds for different load, therefore, the dynamic behavior of the system is basically unaffected by the change in operating conditions. In both the conditions, the output is maintained constant as per feedback, gain (beta) which gives controlled gate signals to MOSFET.

Antonio et.al. in [20] analyzes a very high-voltage-gain single-stage boost converter operating at the boundary between continuous conduction mode (CCM) and discontinuous conduction mode (DCM). A 12V car battery is provided as input to the converter and it attains 1200V with a voltage gain of 100. A hysteretic comparator is used here in the control loop which prevents the risk of modulator saturation and facilitates the operation at the mentioned boundary. For analysis of the dynamic behavior of the switching regulator, Sliding-mode control theory is applied. This also establishes the system stability condition. The material used in the converter is silicon carbide (Sic) for the power switch.

IV. CONCLUSION

The PID Controller technique cannot meet requirements for a fast dynamic response, high control precision and if there are uncertainties then the stability of this technique cannot be guaranteed. Nonlinear controllers like model predictive control (MPC) and fuzzy controllers are effective while most are complex and they are difficult and expensive for practical applications. Although clear benefits of sliding mode control is summarized in above literature. There are many converter topologies for achieving high voltage, therefore sliding mode control can be used in other topologies of converter but designing of control technique becomes difficult in higher order topologies.

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