Sliding-mode controller for a three level DC-DC Boost converter

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Abstract- **Renewable energy systems have been using to provide voltage to the Boost Converter which has to be boosted up before being inverted and connected to the grid. The controller technique should provide good voltage regulation and suitable for the Boost DC-DC conversion purposes. There are many controller techniques are proposed for MBC. This paper provides Reduce order model for a three level Boost Converter and focused on SMC without integrator, with integrator and double integrator, Results have been analyzed.**

Keywords- Multilevel boost converter (MBC), Sliding mode controller (SMC).

I. INTRODUCTION

Today, fossil fuels are being used globally. Where, these fuels causes the greenhouse gas effect and environment pollution, which are opposed by the concept of sustainable development. In order to reduce the utilization of fossil energy, the renewable energy generation systems are being used in industries, mainly in electrical generation system (REGSs). Unfortunately, these REGSs generate low level DC output voltage which is not sufficient for connecting to the power grid. In order to meet the high bus voltage demand, the dc-dc boost converter was developed in to the REGSs. Conventional boost converters only give a restricted voltage gain because of parasitic components and it has stability issue if it works in the high duty ratio. To overcome this problem many high output voltage gain dc-dc boost converters are proposed but they are complex in structure. Besides, design of controller for these converters is complex so multilevel dc-dc boost converters are introduced which are simple in structure and number of levels can be extendable as needed. They are capable of providing high voltage gain with small duty ratio. DC-DC converters are nonlinear systems, which convert sources of direct current from one voltage level to another voltage level, with the properties of nonlinearity, variable structure and non-minimum system of the boost converter, designing the controller for such converter is challenging task. There are various control techniques such as, PWM controller, PID controller, PI controller, sliding mode controller, Fuzzy artificial neural network (ANN).

The controller requires a control technique that should maintain the stability against variations in input voltage and load. Sliding mode control is an effective control technique for a DC-DC converter; it can provide robustness and stability against large signal disturbances and circuit component uncertainties. SMC technique is composed of two modes one is reaching mode and another one is sliding mode. In this paper a sliding mode controller for a three level DC-DC boost converter is proposed. The sliding surface is formed using the inductor current error and the integral of the output voltage error. The main advantage of sliding mode controller is easy to implement as compared to the other non linear control methods, because of this property it is more suitable for the industrial applications in non linear system.

II. BACKGROUND

In this section, we briefly discuss the works which is similar to our approach.

Wentao Jiang, chok You Chan.[1] have introduced Hysteresis based sliding mode control to regulate DC-DC converter which provides robustness and stability against large scale perturbation and circuit component variations. Developed suitable reduced order state space model for the converter shows the validity and feasibility of controller under various operating conditions.

Julio C, Rosas-Caro, Juan M. Ramirez, Pedro Martin- Garcia-vite.[2] have developed a DC-DC multilevel boost converter using one inductor, one switch, 2N-1 capacitors and 2N-1 diodes for N+1 levels . Proposed converter to be used as DC link in applications which can able to maintain the same voltage in all the output levels and control the input current.

J. C. Mayo-Maldonado, R. Salas-Cabrera, H. Cisneros-Villegas, M. Gomez-Garcia, E. N. Salas-Cabrera. R. Castillo-Gutierrez and O. Ruiz-Martinez.[3] have proposed full order nonlinear dynamic model for a DC-DC multilevel boost converter. Output voltage is controlled by input-output feedback linearization technique.

Swarada S. Muley, Ravindra M. Nagarale. [4] Have discussed Pulse Width Modulation based Sliding Mode Controller operating in Continuous Conduction Mode for DC-DC boost converter. The performance and properties of Sliding Mode Controller is compared with other converters such as Proportional Integral Derivative (PID) controller and Proportional Integral (PI) controller. Shown sliding mode controller provides better voltage regulation.

Siew-Chong Tan, Y.M. Lai, Chi K. Tse.[5] this paper developed “Indirect Sliding Mode Control of Power converters Via Double Integral Sliding Surface” use the hysteresis-modulation based sliding mode controller by incorporating additional integral term as state variable into the controller. Shown that proposed controller can achieve regulation of output voltage at low switching frequency.

Lokesh Bulla, V Nattarasu.[6] have done comparative study of different control techniques for multilevel DC-DC boost converter. Results shows that performance of PID controller is best comparing to others such as Proportional integral (PI) controller and sliding mode controller.

III. PROPOSED WORK

The SMC is applied to the three level dc-dc boost converter. Fig.1 shows the electrical diagram of three level boost converter.

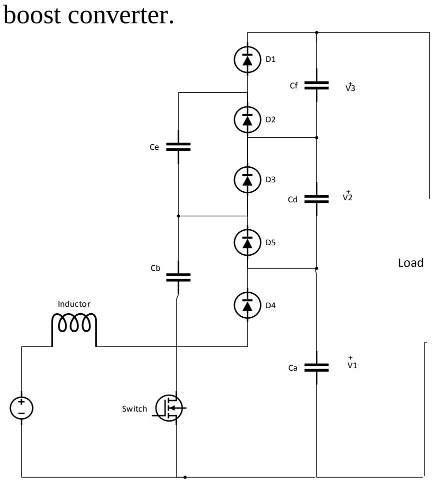

Fig.1. Electrical diagram of three level boost converter.

A reduced order nonlinear dynamic model for the three level boost converter is shown. The steady state equation of the three level boost converter is same as the steady state equation of the conventional boost converter. The output voltage can be obtained by multiplying the output voltage equation of basic multilevel converter and the number of stages in multilevel boost converter. Fig.2 and Fig.3 shows the topologies of the three level DC-DC boost converter when switch is on and switch is on.

Assume, the three level boost converter operates in continuous conduction mode. By applying basic principle, by equating $C = C_a = C_b = C_d = C_e = C_f$. Then by equating ,

$$C_{equ2} = C_a, \qquad C_{equ1} = \frac{C(f)*C(e)}{C(f)+C(e)} + \frac{C(a)*C(b)}{C(a)+C(b)},$$

$$C_{equ3} = \frac{C(f)*C(e)}{C(b)+C(d)} + \frac{C(f)*C(e)}{C(b)+C(d)}$$

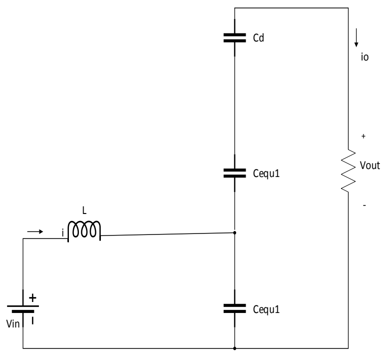

Fig.2. Reduced order equivalent circuit when the switch is ON

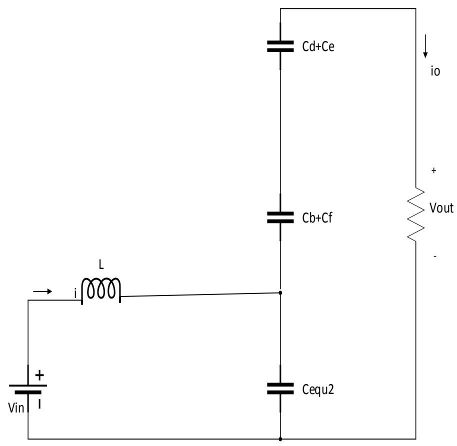

Fig.3. Reduced order equivalent circuit when the switch is OFF

Every capacitor output voltage is considered because the circuit output voltage is divided by the number of capacitors at the output. By applying voltage balancing feature to the boost converter

$$V_a = V_b = V_c = \frac{V_{out}}{3} \quad (1)$$

From the circuit shown in Fig.1 and equation 1, the dynamics for inductor current and output voltage can given as,

$$L\frac{di}{dt} = E \;\;, \;\; Cequ1\frac{dv}{dt} = -\left(\frac{3}{R}\right) * V_{out} \quad (2)$$

During switch is open

$$L\frac{di}{dt} = -\frac{V_o}{3} + E, Cequ2\frac{dv}{dt} = i - \left(\frac{3}{R}\right) * V_{out} \quad (3)$$

By combining the above equations,

$$L\frac{di}{dt} = -(1 - Uavg)\left(\frac{V_{out}}{3}\right) + E, [Cequ1\, U + (1 - Uavg)Cequ2]\frac{dv}{dt}(1 - Uavg)i - \left(\frac{3}{R}\right) * V_{out} \quad (4)$$

Where $Uavg$ denotes the average input, it is actually the duty cycle of the switch.

By choosing inductor current and output voltage as the state variables, equation 4 can be expressed in state space form as given below.

$$\frac{d}{dx}[i\ V\ ]^I = \begin{bmatrix} 0 & -\dfrac{1}{3L} \\ \dfrac{1}{C(t)} & -\dfrac{3}{R\,C(t)} \end{bmatrix} [i\ V\ ]^I + \begin{bmatrix} \dfrac{V}{3L} \\ \dfrac{i}{C(t)} \end{bmatrix} [U_{avg}] + \begin{bmatrix} \dfrac{E}{L} \\ 0 \end{bmatrix}$$

IV. PROPOSED SLIDING MODE CONTROLLER

The main control objective in power converter is to track the given constant reference voltage V_{ref} by forcing V_{out}.

$$V_{out} = V_{ref}$$
$$U_{ss} = 1 - \frac{2V_{in}}{V_{ref}}$$
$$I_L = I_{Lref} - \frac{{V_{ref}}^2}{V_{in}R_o} \quad (5)$$

Designing of sliding mode control requires two stages :
1) Choose a sliding surface that gives asymptotically the desired dynamic in sliding regime and
2) Designing the control law to achieve this surface. Designing the SM requires to describe the system by state space equations.

$$\dot{y} = Ax_1 + Bx_2 + D$$

Where

$$y = [il, V_{0ut}]^t$$

The matrices A, B and D are given as

$$A=\begin{pmatrix} 0 & \frac{-1}{2L} \\ \frac{1}{C_e} & \frac{-2}{R_0 C_e} \end{pmatrix} \quad B=\begin{pmatrix} \frac{V_{0ut}}{3L} \\ \frac{-iL}{C_e} \end{pmatrix} \quad D=\begin{pmatrix} \frac{V_{in}}{L} \\ 0 \end{pmatrix}$$

After obtaining the state space matrix, the further step is to design the controller. For switched converters it is suitable to have a control law adopts a switching function such as

$$x_2=\begin{Bmatrix} 1 & where\ s > 0 \\ 0 & where\ s < 0 \end{Bmatrix}$$

Where s is the instantaneous state variable's trajectory and it s given as,

$$S= a_1y_1 + a_2y_2 + ay_3 = J^TY$$
$$\text{With } J^T=[\,a_1 + a_2 + \ a_3]$$

Where $a_1,\ a_2\ and\ \ a_3$ are the control parameters termed as sliding coefficients in sliding mode control. By forcing S=0, sliding surface can be obtained. Finally, the mapping of the equivalent control functions onto the duty ratio d.

$$0 < d = \frac{V_c}{V_{ramp}} < \quad 1$$

Following relationship are obtained for the control signal V_c and ramp signal V_{ramp}, where

$$V_c = U_{equ} = -\beta L\left[\left(\frac{a_1}{a_2}\right) - \left(\frac{1}{R_1 c}\right)\right] i_c + LC\left(\frac{a_3}{a_2}\right)(V_{ref} - \beta) + \beta(V_{out} - V_{in})$$
$$V_c = kp_1 i_c + kp_2(V_{ref} - \beta V_{out}) + \beta(V_{out} - V_i)$$
$$kp_1 = \left(\frac{a_1}{a_2}\right) - \left(\frac{1}{R_1 c}\right) \quad \& \quad kp_2 = LC\left(\frac{a_3}{a_2}\right)$$
$$V_{ramp} = \beta(V_{0ut} - V_{in})$$

V. IMPLEMENTATION AND RESULTS

In this section the implementation and performance of the three level boost converter without controller and with controller are discussed. Simulations were done by using Matlab\simulink software. Chosen parameter values are L=180μH, C=150μF.
The design specifications considered in this project are as follows

- Input voltage = 40V
- Output voltage = 300V
- Output power = 600W

- Output current = 2A
- Switching frequency = 50 kHz

A. Simulation block and waveforms of TLBC without controller:

Fig.4 shows the simulink block of three level boost converter. Waveforms of TLBC without controller are shown in Fig.5.

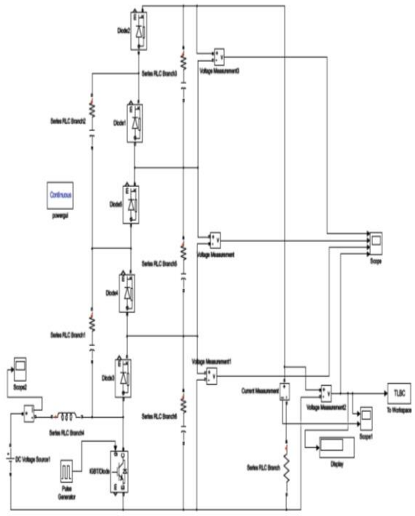

Fig.4. Schematic of open loop power circuit simulation in Simulink

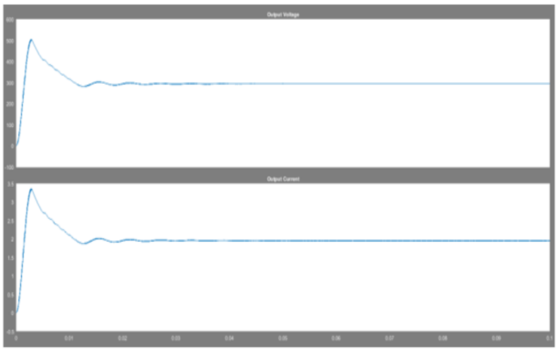

Fig.5. Output voltage and current waveforms of the converter without controller

In the wave form shown in Fig.5 rise time of TLBC waveform is fast i.e 1ms, but settling time is more i.e 20ms and steady state error is more compare to with controller.

B. Simulation block and waveforms of TLBC with Sliding Mode controller (without integrator)

Simulink block of SMC (without integrator) is shown in Fig.6.The voltage and current waveforms of TLBC with SM controller are shown in Fig.7. SMC is designed by choosing surface constant, $kp_1 = 3$ and $kp_2 = 30$

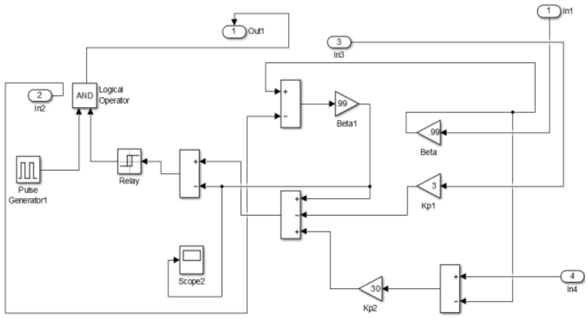

Fig.6. Schematic of the SM controller (without integrator) block for power circuit

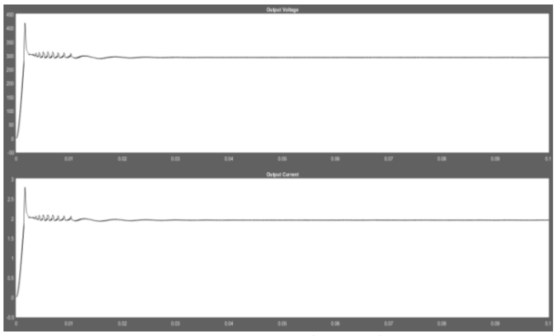

Fig.7. Output voltage and current waveforms of the converter with SM controller (without integrator)

Compare to Output wave forms of converter without controller the overshoot and settling time is less in output wave forms of converter with Sliding Mode controller (without integrator) as shown in Fig,7.

C. Simulation block and waveforms of TLBC with Sliding Mode controller (with single integrator)

Simulink block of SMC (with single integrator) is shown in Fig.8.The corresponding voltage and current waveforms are shown in Fig.9.

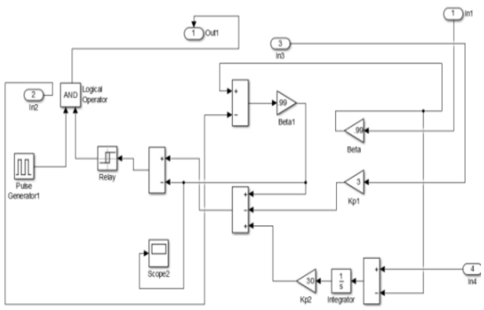

Fig.8. Schematic of the SM controller (with integrator) block for power circuit

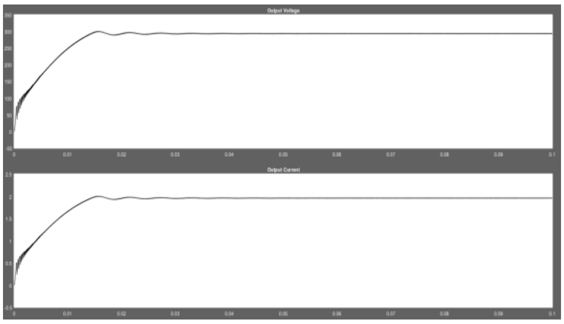

Fig.9. Output voltage and current waveforms of the converter with SM controller (with integrator)

In Fig.9 overshoot is less in output wave forms of converter with Sliding Mode controller (with integrator). But compare to without controller and with Sliding Mode controller (without integrator) raising time and settling time in Sliding mode controller (with integrator)is more.

D. Simulation block and waveforms of TLBC with Sliding Mode controller (with double integrator)

Simulink block of SMC (with double integrator) is shown in Fig.10.The corresponding voltage and current waveforms are shown in Fig.11.

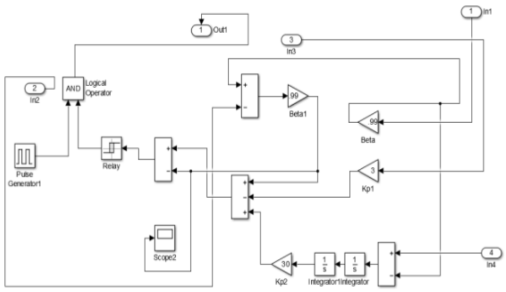

Fig.10. Schematic of the SM controller (with double integrator) block for power circuit

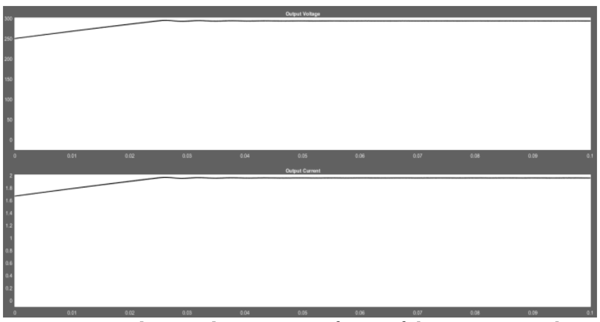

Fig.11 Output voltage and current waveforms of the converter with SM controller (with double integrator)

Comparison of Controllers	**Measured parameters**				
	Settling time in ms	***Rise time in ms***	***Peak time in ms***	***Overshoot in percentage***	***Steady state error in volts***
Without controller	20	1	3	73%	7
With SMC(without integrator)	16	1.1	2	43%	7
With SMC(with single integrator)	19	10	15	2.7%	6.5
With SMC(with double integrator)	120	30	125	0.94%	7

The main advantage of this controller is very less overshoot. From the Table.1 we can observe that overshoot is 0.94%, but settling time is very slow i.e 120ms. Rise time is more compare to other converters i.e 30ms and peak time is 125ms

Table1. Comparison table

VI. CONCLUSION

In present work sliding mode controller (SMC) without integrator, sliding mode controller (SMC) with integrator and sliding mode controller (SMC) with double integrator is designed for three level DC-DC boost converter. Converter modeling and converter design has been discussed Simulations were carried out using Matlab\Simulink software. The robustness of sliding mode controller is tested and results are analyzed, the sliding mode controller with double integral is the additional integral term, which provides the less steady state error but settling time is more compare to other converters.

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