Comparision of different control techniques for three level DC-DC boost converter

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Abstract— This paper present the Design and simulation of Multilevel DC/DC Boost converter operating in continuous conduction mode using Proportional Integral Derivative (PID) controller. The performance and properties of Proportional Integral Derivative (PID) controller is compared with pulse width modulation based sliding mode controller (SMC) and Proportional Integral (PI) controller. Simulation results show that the PID control scheme provides good voltage regulation and is suitable for multilevel boost DC-to-DC conversion purposes. The derived SMC controller/converter system is suitable for any changes on line voltage and parameters at input keeping load as a constant.

Keywords: Multilevel DC/DC Boost converter, Proportional Integral Derivative (PID) controller, sliding mode controller (SMC), Proportional Integral (PI) controller.

I. INTRODUCTION

The power converter has become an essential component in the design of clean energy systems. It is used in photovoltaic systems, wind energy systems, hybrid vehicles, portable devices and power supply. Multilevel converter is a good candidate for the medium and high power applications. It is one of the most used converter topologies because of their many advantages, such as their low harmonic distortion, low voltage stress on power switches, high output voltage gain and high efficiency [1]-[2]. Recently, Three level Boost DC-DC Converter (TLBC) was proposed (Figure 1)[3]-[4]. Comparing with the conventional boost DC-DC converter, TLBC presents several advantages such as self voltage balancing and without using an extreme duty ratio its gives high voltage gain. TLBC is switched nonlinear system. These controllers are designed the usage of conventional linear manage strategies where in the small sign version is derived from the linearization round a nominal factor of area nation average model. A suitable controller for , three level boost converter have to deal with its intrinsic non linear and input voltage and load changes, making sure that stability at any operating condition. Because of its Switched nature, three level boost converter can be considered as a variable structure system. Therefore it can be managed the usage of well-known techniques of sliding mode controller (SMC) [4]-[5], PID control and PI control. SMC has been widely used and correctly carried out in DC-DC converters. The principle advantages of SMC on conventional manipulate are robustness, accurate dynamic reaction, simple implementation and low implementation cost.

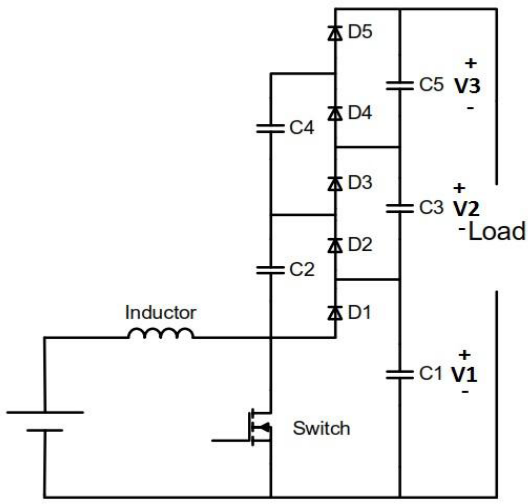

Figure 1: The Electrical Diagram Of Three Level Boost Converter

II. MODELING OF THE CONVERTERS

This section we will be show a reduced order nonlinear dynamic model design for the proposed three stage dc-dc boost converter. The steady state equations of the three level boost converter are similar to the steady state equations of the conventional boost converter. The average output voltage equation of the basic multilevel boost converter is multiplied by the number of stages of the multilevel boost converter. Figure 3 and Figure 4 depict respectively the equivalent circuits for three level boost converter when switch is ON and switch is OFF.

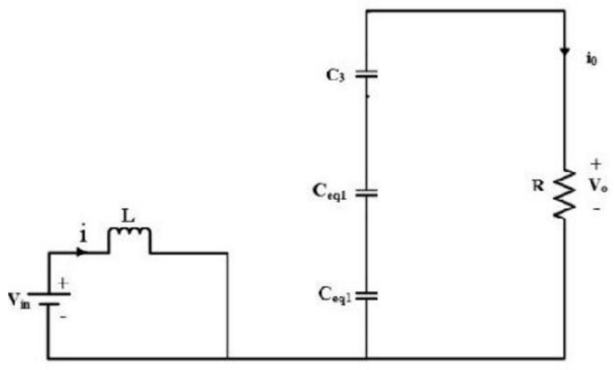

Figure 2: The Reduced Order Model When the Switch is closed

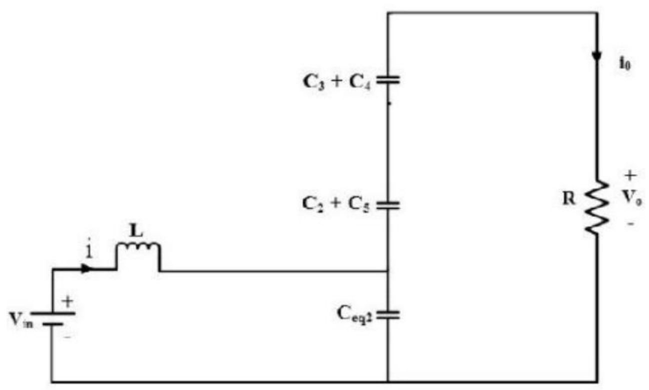

Figure 3: The reduced order model when the switch is open

It is assumed that TLBC operates in continuous conduction mode (CCM) and all components to be ideal. By using basic principle and equating $C = C_1 = C_2 = C_3 = C_4 = C_5$, the equivalent capacitor becomes , $C_{eq2} = C_1$, $Ceq1 = \frac{C(5)*C(4))}{C(5)+C(4)} + \frac{C(1)*C(2)}{C(1)+C(2)}$, $Ceq3 = \frac{C(5)*C(4)}{C(2)+C(3)} + \frac{C(5)*C(4)}{C(2)+C(3)}$

and further to this the voltage across every capacitor at the output might be taken into consideration because the circuit output of voltage divided by the number of capacitors at the output i.e $\frac{V}{N}$. In terms of equation,

$$V_1 = V_2 = V_3 = V/3 \quad \text{......... (1)}$$

the circuit shown in Figure1 and equation (1), the dynamics for the inductor current and output voltage can be written as,

When Switch is closed

$$L\frac{di}{dt} = E$$

$$\text{.............. (2)}$$

$$Ceq1\frac{dv}{dt} = -\left(\frac{3}{R}\right) * V$$

When Switch is Open

$$L\frac{di}{dt} = -\left(\frac{V}{3}\right) + E$$

$$\text{........... (3)}$$

$$Ceq2\frac{dv}{dt} = i - \left(\frac{3}{R}\right) * V$$

From above Equation can be written in combine form that is valid for switch ON and switch OFF state

$$L\, di/dt = -(1 - Uav)(V/3) + E$$

$$\text{........... (4)}$$

$$[Ceq1\ U + (1 - Uav)\, Ceq2]\frac{dv}{dt} = (1 - Uav)\, i - \left(\frac{3}{R}\right) * V$$

Where the average input denoted by U_{av} is actually the duty cycle of the switch. Let us consider $C_{eq1} U_{av} + (1 - U_{av}) C_{eq2}$ as $C_{(t)}$the time varying parameter ((Eq(4))

$$L\frac{di}{dt} = -\left(\frac{V}{3}\right) + \left(\frac{V}{3}\right) Uav + E$$

$$\text{............(5)}$$

$$C(t)\frac{dv}{dt} = i - i * Uav - \left(\frac{3}{R}\right) * V$$

Using the inductor current and output voltage as state variables, above Equation can be written in state space form as expressed below

$$\frac{d}{dx}[i\ V]^I = \begin{pmatrix} 0 & -\frac{1}{3L} \\ \frac{1}{C(t)} & -\frac{3}{RC(t)} \end{pmatrix} [i\ V]^I + \begin{pmatrix} \frac{V}{3L} \\ \frac{i}{C(t)} \end{pmatrix} [u_{av}] + \begin{pmatrix} \frac{E}{L} \\ 0 \end{pmatrix}$$

III. CONTROL TECHNIQUES USED IN THREE LEVEL DC-DC BOOST CONVERTER

A control technique suitable for three level DC-DC converter must match with the nonlinearity and input voltage and load variations, making sure stability in any operating condition. There are various control techniques based on, fuzzy logic, artificial neural network (ANN), sliding mode control (SMC), PI control, PID control and P control. In this paper three level DC-DC boost converter we compare the properties of sliding mode control, PI control and PID control

A. Proportional Integral (PI) controller:

P-I controller is particularly used to eliminate the steady state error came from P control. However, in terms of the speed of the output and overall stability of the system, it has a negative effect. This controller is widely used in area where speed of the system is not a problem. Since PI controller has no ability to predict the further errors of the system it cannot reduce the rise time and eliminate the oscillations.

B. Proportional Integral Derivative (PID) controller:

Three control techniques namely proportional, integral and derivative are combined to get proportional integral derivative. PID controller has the best control dynamics including zero steady state error, short rise time and higher stability. The necessity of using of a derivative gain component in addition to the PI controller is to remove the overshoot. One of the main advantages of the PID controller is, it can be used with higher order system process including more than single energy storage. The constant used in PID are K_p, K_i and K_d.

C. Sliding Mode Control:

The sliding mode control provides a method for designing a system so that if any variations in parameter and external disturbances the system is insensitive. The technique consists of two modes (Figure. 4). Namely Reaching mode and sliding mode .The reaching mode in which the trajectory slide towards the switching surface from initial point. The other is the sliding mode in which the trajectory slides along the switching surface. And switching surface equation is defined during this sliding mode and therefore it is independent of the parameters.

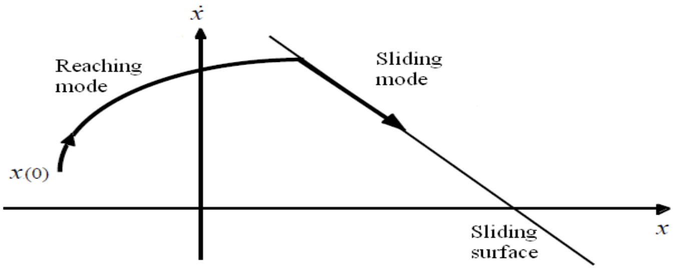

Figure 4: Sliding control modes.

The control objective in power converter is to force V_o to track a given constant reference voltage V_{ref}

$$\left.\begin{aligned} V_o &= V_{ref} \\ U_{ss} &= 1 - \frac{2V_{in}}{V_{ref}} \\ I_L = I_{Lref} &= \frac{V_{ref}^{\ 2}}{V_{in} R_o} \end{aligned}\right\} \dots\dots\dots\dots\dots (6)$$

The design of SM control is done in two stages: 1) choose a sliding surface that provides asymptotically the desired dynamic in sliding regime and then 2) the control law is designed to achieve this surface [7]-[8]. The first step in the design of SM control is describing the system by state space equations.

$$\dot{x} = Ax + Bu + D$$

Where

$$x = [iL\,, vo]^t$$

And the matrixes A, B and D are given by

$$A = \begin{pmatrix} 0 & \frac{-1}{2L} \\ \frac{1}{Ceq} & \frac{-2}{Ro\ Ceq} \end{pmatrix} \quad B = \begin{pmatrix} \frac{vo}{3L} \\ \frac{-iL}{Ceq} \end{pmatrix} \quad D = \begin{pmatrix} \frac{vin}{L} \\ 0 \end{pmatrix}$$

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

$$u = \begin{cases} 1 & where\ \ S > 0 \\ 0 & where\ \ S < 0 \end{cases}$$

Where S is the instantaneous state variable's trajectory and is described as,

$$S = \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 = J^T X$$

$$With, \quad J^T = [\alpha_1\ \alpha_2\ \alpha_3]$$

Where, α_1, α_2 and α_3 are control parameter of sliding mode control and termed as sliding coefficients. A sliding surface can be obtained by forcing, S = 0. Finally, the mapping of the equivalent control function onto the duty ratio control d.

$$0 < d = \frac{Vc}{Vramp} < 1$$

Gives the following relationship for the control signal V_c and ramp signal V_{ramp}, where

$$V_C = U_{equ} = -\beta L \left[\left(\frac{\alpha_1}{\alpha_2}\right)-\left(\frac{1}{R1C}\right)\right] i_C + LC\left(\frac{\alpha_3}{\alpha_2}\right)(V_{ref} - \beta Vo) + \beta(V_o - V_i)$$

$$V_C = -kp1 i_C + kp2(V_{ref} - \beta Vo) + \beta(V_o - V_i)$$

$$kp1 = \left(\frac{\alpha_1}{\alpha_2}\right) - \left(\frac{1}{R1C}\right) \quad \& \quad kp2 = LC\left(\frac{\alpha_3}{\alpha_2}\right)$$

$$V_{ramp} = \beta(V_O - Vi)$$

IV. SIMULATION RESULTS

The simulations were performed with the following parameter
Values: L = 180 μH, C = 150 μF. The reference current i_{ref} is calculated from equation (Eq. (6)).

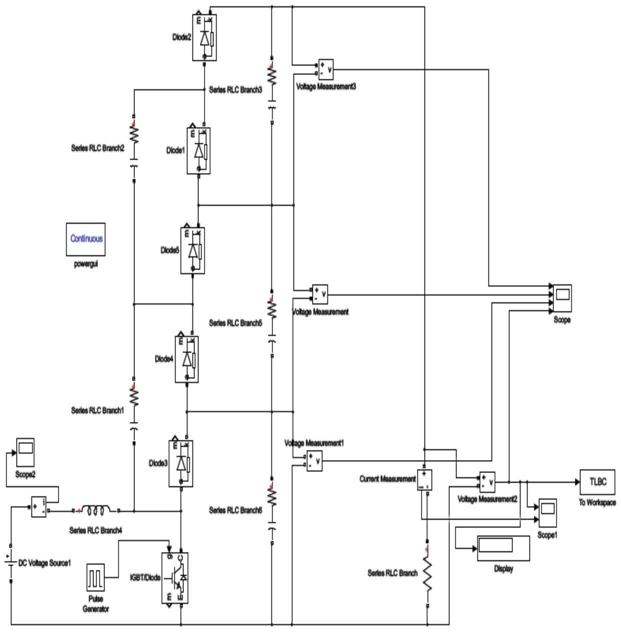

Figure 5: Simulink Block of TLBC

A. Simulink Block and Waveforms of TLBC without controller

The waveform of three level boost converter without controller is shown below. Without controller TLBC has more overshoot.

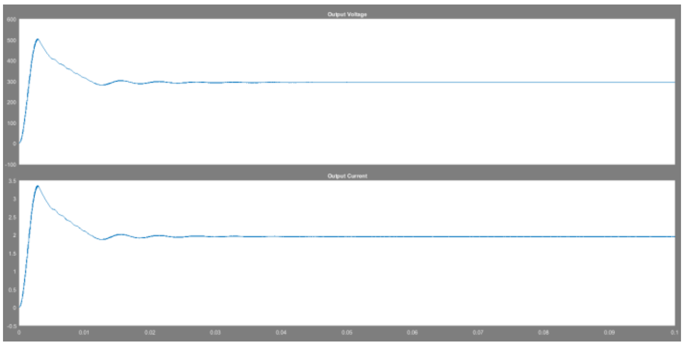

Figure 6: TLBC Output Voltage and Current Wave Forms

B. Simulink Block and Waveforms of TLBC with PI controller

The waveform of three level boost converter with PI controller is shown below. TLBC with PI controller has less overshoot compare to without controller. PI control is design with PI constant, K_p =0.0054 and K_i= 3.7147e-3

Figure 7: PI Controller Output Voltage and Current Wave Forms

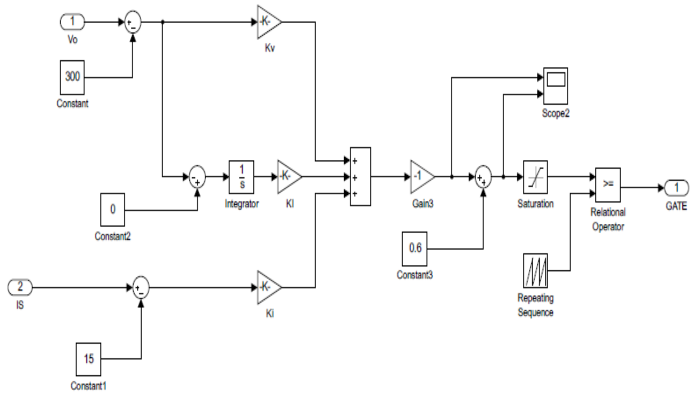

Figure 8: Simulink Block of PI Controller

C. Simulink Block and Waveforms of TLBC with PID controller

The waveform of three level boost converter with PID controller is shown below. TLBC with PID controller has no overshoot, PID controller is designed with PID constant, K_p =0.004, K_i= 160.5e-6 and K_d= 1e-6

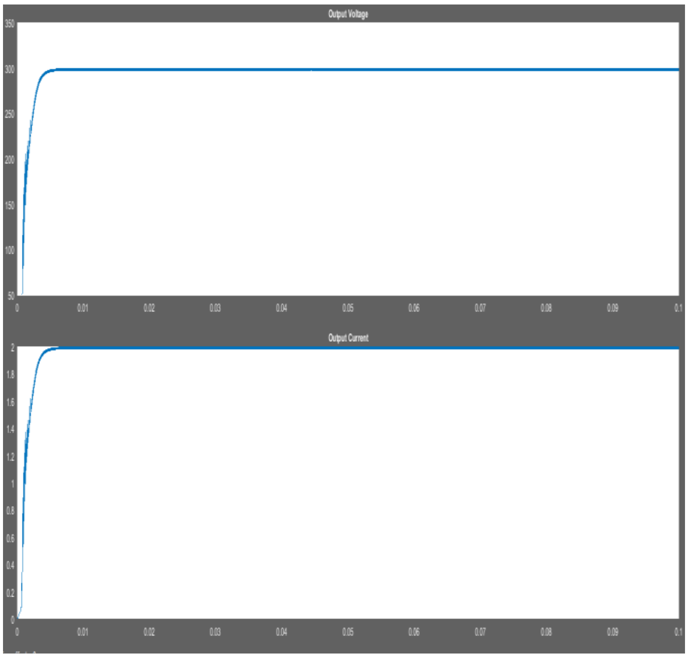

Figure 9: PID Controller Output Voltage and Current Wave Forms

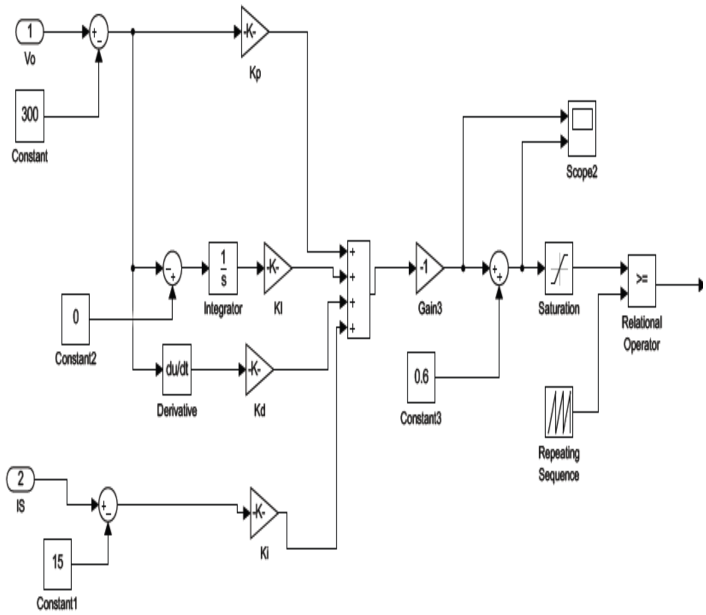

Figure 10: Simulink Block of PID Controller

D. Simulink Block and Waveforms of TLBC with SMC controller

The waveform of three level boost converter with SM controller is shown below. TLBC with SM controller has little overshoot compare to PID .SM control is design with surface constant, K_{p1} =3 and K_{p2} = 30

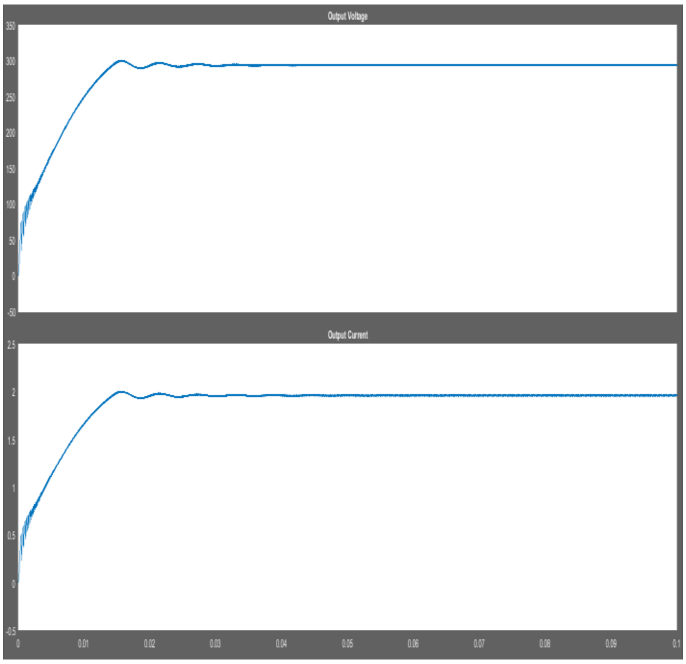

Figure 11: SMC Controller Output Voltage and Current Wave Forms

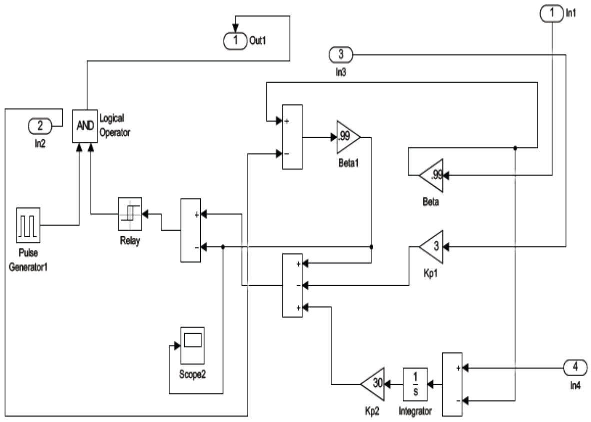

Figure 12: Simulink Block of SMC Controller

Table 1. Comparison between Sliding Mode Control, PI Control & PID Controller

Controller	***Settling time in ms***	***Rise time in ms***	***Peak time in ms***	***Overshoot in volt***	***Steady state error in volt***
Without controller	20	1	3	204	7
PI controller	10	4	2	25	4
PID controller	6	6	6	0	1
SM controller	15	10	16	0.5	7

V. CONCLUSION

In this paper PID control, PI control and sliding mode controller (SMC) is designed for three level boost DC-DC converter. After converter modelling and controller design, the simulations have been carried out in Matlab/Simulink software. The simulation result gives the validity of the all converter controller model. The robustness of sliding mode control is tested. The comparison of PID Controller with PI Controller and SMC has analyzed and the performance of PID is good compare to other controller in this three level boost converter.

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