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PERFOEMANCE EVALUATION OF PI, PID CONTROL & SM CONTROL FOR BUCK CONVERTER USING MATLAB/SIMULINK

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Abstract: **As the characteristics of power sources and electrical/electronic loads become more widely varied, nonlinear, and unpredictable, the control of the power converters that provide the necessary power processing functions will play an important role in optimizing performance and maintaining the needed robustness under various operating conditions. The SM control is naturally well suited for the control of variable structure systems like power converters. Buck converter is variable structure systems. So, it is appropriate to apply SM control on Buck converter. The reported experimental works focused attention on performance evaluation of Buck converter. Simulation results show the characteristics of Buck Converter in close loop mode. The work compares the performances of a Buck converter controlled by conventional PI/PID controller and SM controller.**

Keywords: **DC-DC converter, BUCK converter, PI/PID controller, SM controller.**

I. INTRODUCTION

DC–DC converters are power electronic circuits that accept DC input voltages or currents and produce DC output voltages or currents. This power conversion process is divided as step down conversion (Buck converter), step up conversion (Boost converter), and step up-down conversion (Buck-Boost converter). DC-DC converters are important in portable devices such as cellular phones and laptops. The Buck Converter is most widely used DC-DC converter topology in power management and voltage regulation application. These applications requires that the converter operates with a small steady-state output error, fast dynamical response, low overshoot, and low noise susceptibility, while maintaining high efficiency and low noise emission. They can convert a voltage source in to lower regulated voltage source. For example for computer system voltage needs to be step down and lower voltage needs to be maintained. For this Buck Converter needs to be used. Furthermore, Buck Converter provides longer battery life for mobile systems. Buck regulator is also used as switch mode power supplies for baseband digital core and the RF power amplifier. Suppose we want to use a device with low voltage level and if devices such as laptop or mobile charger directly connected to the supply at home then it may be damaged or not work properly due to overvoltage and over current fluctuation. To avoid this unnecessary damage of devices or

equipment's we need to convert the voltage level to the required voltage level and maintain it at same level. In this project the Buck Converter configuration of DC-DC converter is chosen for study. It is suitable for lower power application due to low voltage and current at output.

The main objective of this project is to design a buck converter to convert a dc input voltage to the required lower dc output voltage level for lower power application to solve the problem of voltage regulation and high power loss of the linear voltage regulator circuit. Basically we design a buck converter circuit using PI control technique to get the stable output from a given input. The converter uses a switching scheme which operates the switch MOSFET in cutoff and saturation region to reduce power loss across MOSFET. Then, the output voltage is controlled using SM Control technique to get the desired output voltage level. The design is based on low power application such as laptop charger, mobile charger etc. The circuit is simulated using MATLAB/SIMULINK software to obtain desired response.

II. MATHEMATICAL FORMULATION

A. Sliding co efficient derivation.

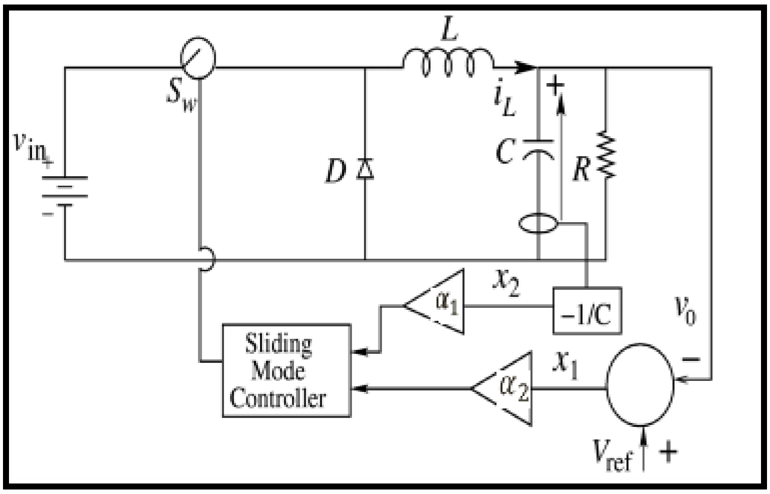


Figure: 1: basic structure of an SMC Buck converter system

A typical SM controller for switching power converters has two control modes: voltage mode and current mode. Here, voltage mode control is employed, i.e. output Voltage V_o is the parameter to be controlled. Figure 1 shows the schematic diagram of a SM voltage controlled buck converter.

In SM controller, the controller employs a sliding surface to decide its input states to the system. For SM controller, the switching states U which corresponds the turning on and off of the converter switch is decided by sliding line. The sliding surface is described as a linear combination of the state variables.

The sliding line acts as a boundary that splits the phase plane into two regions. Each of these regions is specified with a switching state to direct the phase trajectory toward the sliding line. When the phase trajectory reaches and tracks the sliding line towards the origin, then the system is considered to be stable, i.e.,$X_1 = 0$ & $X_2 = 0$.

Substituting $X_2 = \dot{X}_1$ in equation of sliding manifold

$$\alpha_1 x_1(t) + \alpha_2 x_2(t) + \cdots + \alpha_m x_m(t) = 0$$

results in

$$S = \alpha_1 X_1 + \alpha_2 X_1' = 0 \qquad (1)$$

This describes the system dynamic in sliding mode. Thus, if existence and reaching conditions of the sliding mode are satisfied, a stable system is obtained.

To ensure that a system follows its sliding surface, a control law is proposed. In this system, the control law is defined as equation

$$u(t) = \begin{cases} U^{+} & \text{if } S(x,t) > \Delta \\ U^{-} & \text{if } S(x,t) < -\Delta \\ \text{previous state} & \text{Otherwise} \end{cases}$$

The reason for choosing $S > \Delta \,\&\, S < -\Delta$ as the switching boundary is to introduce a hysteresis band which determines the switching frequency of the converter.

The control law only provides the information that the system trajectory is driven toward the sliding line. In order to ensure that the trajectory is maintained on the sliding line, the existence condition of SM operation, which is derived from Lyapunov's second method to determine asymptotic stability, must be satisfied.

The existence condition can be expressed in standard form as:

$$\dot{S} = \alpha^T \dot{X} = \alpha^T (AX + Bu + D) \qquad (2)$$

Using SM theory, equations in two cases gives,

$$\dot{S}_{S>0} = \alpha^T AX + \alpha^T B + \alpha^T D < 0$$

$$\dot{S}_{S<0} = \alpha^T AX + \alpha^T D < 0 \qquad (3)$$

For BUCK CONVERTER $S \rightarrow 0^{+}$ So switch q = 1 & $S \rightarrow 0^{-}$ so switch q = 0. By substituting the matrices A, B, and D, and state variable *x* above inequality becomes:

CASE 1: $\rightarrow 0^{+}$, $\dot{S} < 0$

$$\gamma_1 = \left[\alpha_1 - \frac{\alpha_2}{RC}\right] X_2 - \frac{\alpha_2}{LC} X_1 + \frac{Vref - Vin}{LC} \alpha_2 < 0 \qquad (4)$$

$CASE\ 2: S \rightarrow 0^{-}$, $\dot{S} > 0$

$$\gamma_2 = \left[\alpha_1 - \frac{\alpha_2}{RC}\right] X_2 - \frac{\alpha_2}{LC} X_1 + \frac{Vref}{LC} \alpha_2 > 0 \qquad (5)$$

Defining $\gamma_1 = 0 \,\&\, \gamma_2 = 0$ which satisfying lines with same slope in phase plane by solving these two equations we get sliding coefficient α_1 & α_2.

B. Buck Converter Parameter formula

Duty cycle $D = \frac{T_{on}}{T_{sw}} = \frac{Vout}{Vin}$

Current ripple $\Delta I_L = V_{out}(T_{sw} - T_{on})/L$

Critical value of inductance $L_c = \frac{(1-D)R_L}{2F_{sw}}$

By assuming 10% to 20% ripple current $L = \frac{(V_{in} - V_{out})\frac{D}{F_{sw}}}{I_{ripple}}$

By assuming 1% to 2% ripple voltage in output $C = \frac{\Delta I_L T_{sw}}{8\Delta V}$

III. PI, PID & SMC comparison & its result

Table I: Buck Converter parameter

TOPOLOGY	BUCK CONVERTER
INDUCTOR (L)	69 µH
CAPACITOR (C)	220 µF
DC INPUT VOLTAGE (Vin)	24 V
DC OUTPUT VOLTAGE (Vo)	12 v
LOAD RESISTANCE (RL)	POTENTIOMETER
SWITCH	N- MOSFET (IRF 520)
DIODE	SCHOTTKY DIODE (1N5826)

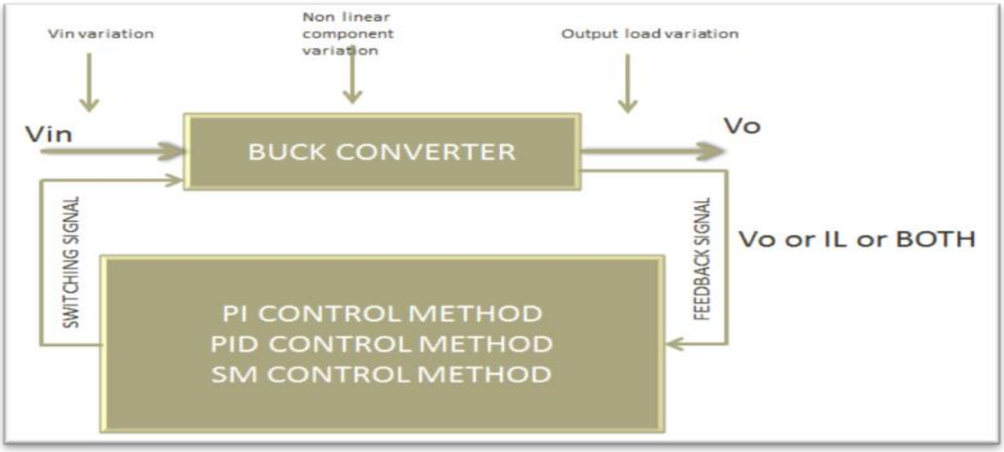
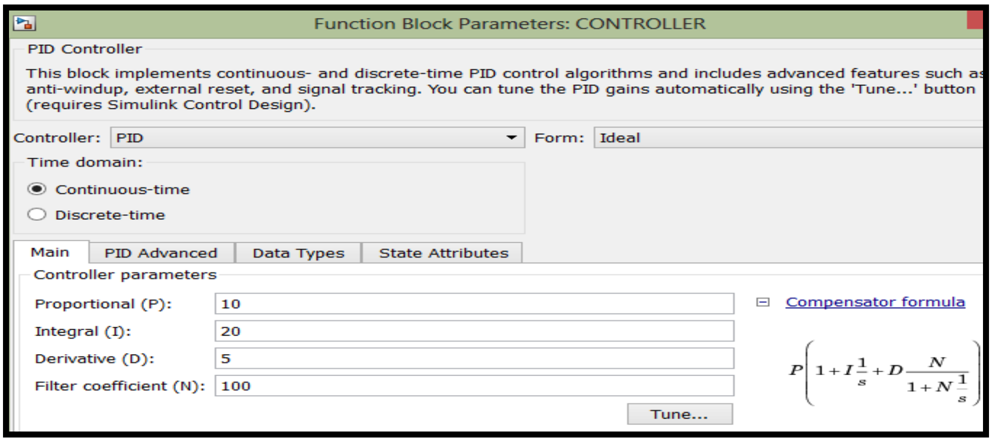


Figure: 2: Types of Controller

All three controllers are compared by evaluating circuit performance by changing load power, line voltage or both parallel, by observing voltage steady state and transient parameters of output voltage response curve. By analyzing effect on o/p voltage settling time, peak overshoot and steady state error by changing load resistance and line voltage comparison done. Below figures shows the simulation work and result analysis is listed in table.



Function Block Parameters: CONTROLLER

PID Controller

This block implements continuous- and discrete-time PID control algorithms and includes advanced features such a
anti-windup, external reset, and signal tracking. You can tune the PID gains automatically using the 'Tune...' button
(requires Simulink Control Design).

Controller: PID

Form: Ideal

Time domain:

● Continuous-time

○ Discrete-time

Controller parameters

Proportional (P): 10

Integral (I): 20

Derivative (D): 5

Filter coefficient (N): 100

$$P\left(1+I\frac{1}{s}+D\frac{N}{1+N\frac{1}{s}}\right)$$

Figure: 3: PID block

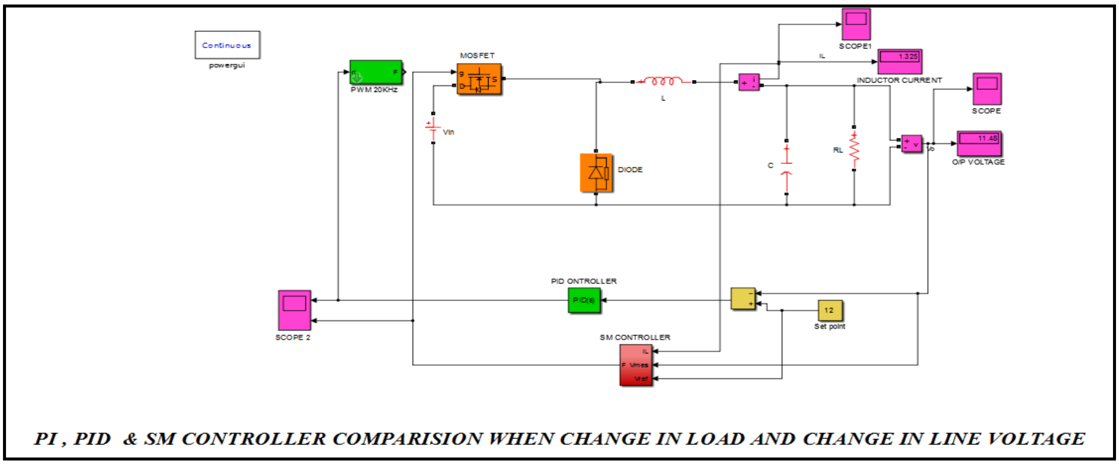


Figure: 4: Controller Simulation model

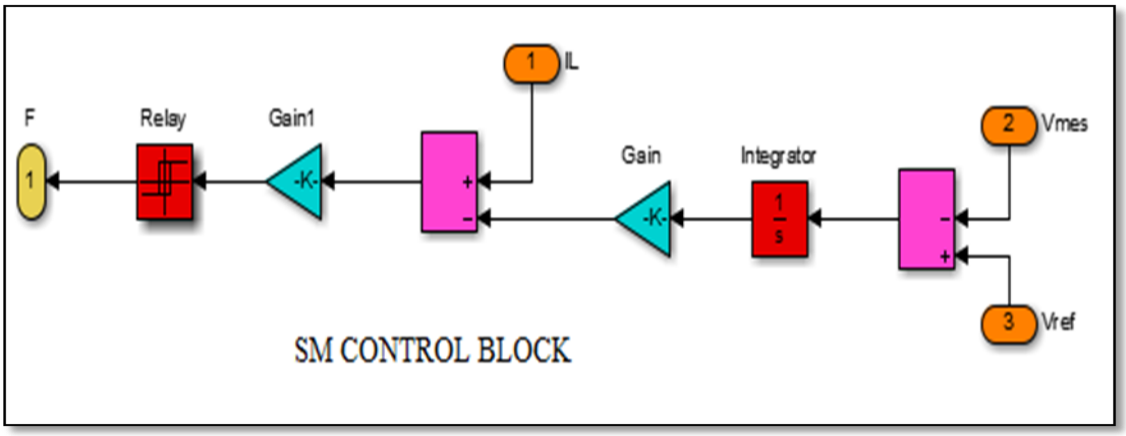


Figure: 5: SM Control block

Table II: change in Load Resistance (RL)

PI CONTROLLER (Vi = 24v) Kp = 10 & Ki = 20				
LOAD RESIS. (RL)ohm	INDUCTOR CURRENT (IL)amp	LOAD VOLTAGE (Vo) volt	PEAK OVERSHOOT volt	SETTLING TIME (Ts) sec
10	2.7*e-4	11.83	21.6	1.5*e-3
13	1.15*e-4	11.84	21.77	2.0*e-3
15	0.46	11.76	21.84	2.3*e-3
18	0.96*e-4	11.80	21.92	2.7*e-3
20	0.95*e-4	11.78	21.96	3.0*e-3

PID CONTROLLER (Vi = 24v) Kp = 10, Ki = 20, Kd = 5				
LOAD RESIS. (RL)ohm	INDUCTOR CURRENT (IL)amp	LOAD VOLTAGE (Vo) volt	PEAK OVERSHOOT volt	SETTLING TIME (Ts) sec
10	1.369	12.49	21.55	1.45*e-3
13	1.044	12.64	21.72	1.8*e-3
15	0.8272	12.74	21.79	2.0*e-3

18	0.4197	12.89	21.87	2.3*e-3
20	0.876	12.98	21.91	2.5*e-3

SM CONTROLLER (Vi = 24V)				
LOAD RESIS. (RL)ohm	INDUCTOR CURRENT (IL)amp	LOAD VOLTAGE (Vo) volt	PEAK OVERSHOOT volt	SETTLING TIME (Ts) sec
10	11.75*e-3	11.56	19.26	6.0*e-3
13	2.28*e-3	12.17	19.73	7.1*e-3
15	1.731	11.97	20.14	10*e-3
18	0.226*e-3	12.14	20.10	13.5*e-3
20	1.70	12.20	20.35	14*e-3

Table III: change in line voltage (Vin)

PI CONTROLLER (RL = 13 ohm) **Kp = 10 & Ki = 20**			
I/P VOLT. (Vi) volt	LOAD VOLTAGE (Vo) volt	PEAK OVERSHOOT Volt	SETTLING TIME (Ts) sec
18	11.88	18.82	1.56*e-3
21	11.86	20.03	1.8*e-3
24	11.84	21.77	2.0*e-3
26	11.84	22.70	2.15*e-3
28	11.82	23.60	2.25*e-3
30	11.71	24.46	2.35*e-3

PID CONTROLLER (RL = 13 ohm) **Kp = 10, Ki = 20 & Kd = 5**			
I/P VOLT. (Vi) volt	LOAD VOLTAGE (Vo) volt	PEAK OVERSHOOT Volt	SETTLING TIME (Ts) sec
18	12.28	18.72	1.42*e-3
21	12.47	20.27	1.65*e-3
24	12.64	21.72	1.8*e-3
26	12.76	22.64	1.9*e-3
28	12.87	23.53	1.95*e-3
30	12.98	24.4	2.1*e-3

SM CONTROLLER (RL = 13 ohm)			
I/P VOLT. (Vi) volt	LOAD VOLTAGE (Vo) volt	PEAK OVERSHOOT Volt	SETTLING TIME (Ts) sec
18	11.94	20.20	7.5*e-3

21	11.46	19.50	8.8*e-3
24	12.17	19.73	7.1*e-3
26	11.28	19.64	9.2*e-3
28	12.19	19.64	12*e-3
30	12.20	20	12.23*e-3

Table IV: change in line voltage (Vin) & load resistance (RL)

CONTROLLER	I/P VOLT. (Vi) volt	LOAD RESIS. (RL)ohm	LOAD VOLTAGE (Vo) volt
PI CONTROLLER	28	15	11.70
	22	20	11.77
PID CONTROLLER	28	15	13
	22	20	12.82
SM CONTROLLER	28	15	12.50
	22	20	12.05

Table V: Result Analysis

CONTROLLERS	**PARAMETERS**		
	PEAK OVERSHOOT	**SETTLING TIME**	**STEADY STATE ERROR**
PI CONTROLLER	HIGHER	LOWER	HIGH
PID CONTROLLER	HIGH	LOWEST	HIGH
SM CONTROLLER	LOWEST	HIGHEST	LOWEST

IV. CONCLUSION

- This paper shows Simulation results compare the design of Buck converter model control using PID Controller and SM controller using signum/Relay function. From the result we justified that SM Control gives better performance characteristics than PI/PID Controller.
- When more accuracy is required & large settling time can be considered then SMC is better choice.
- When low accuracy, low cost, and less complexity is required then PI and PID method is better.

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