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# COMPARETIVE STUDY OF PI CONTROL & SM CONTROL FOR BUCK CONVERTER

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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 controller and SM controller.**

***Keywords–*** **DC-DC Converter, Buck Converter, PI Control,Sliding Mode Control, and SIGNUM function**

## 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 MODEL OF BUCK CONVERTER

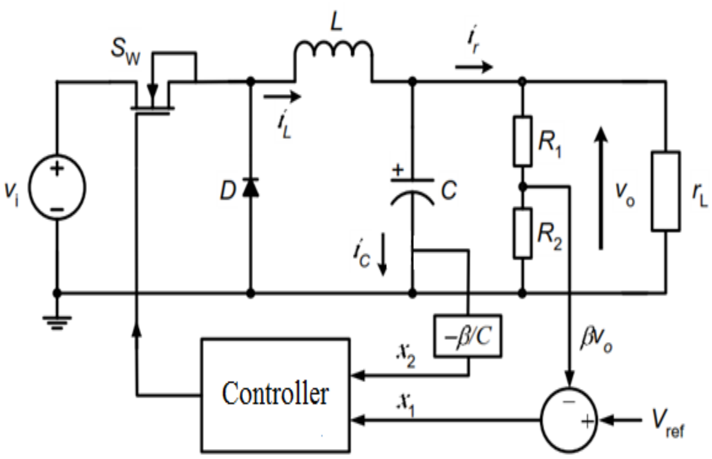


Figure 1:Topology of Buck Converter

A mathematical model of Buck Converter as shown in figure 1 in open loop can be derived using basic circuit analysis laws. The converter is with pure resistive load whose output voltage is to be controlled using SMC. The converter is assumed to be operated in continues current conduction mode. [1]

The state space model of the electrical system can be derived by defining the states as follows:

$x_1 = V_{ref} - \beta V_o$ (1)

$x_2 = \dot{x_1}$ (2)

Where, $\beta = \frac{R_2}{R_1 + R_2}$ is the voltage divider ratio.

$V_{ref} = \beta V_d$, is the reference voltage corresponding to desired load voltage $V_d$.

The SW is the MOSFET switch turned ON or OFF with the output of SM Controller which is in the form of pulses.

Note that when u = 1 means SW is closed and u = 0 means SW is open.

L is an inductor.

C is a capacitor

D is a free-wheeling diode.

$V_o$ is the output voltage.
V is the input voltage.
$r_L$ is the load resistance.

From equation 2

$$x_2 = -\beta \frac{dV_o}{dt}$$

$$x_2 = -\frac{\beta}{C} i_C$$

Where, $i_C$ is the capacitor current which can be measured as shown in figure 1.

Let, $i_L$ and $i_r$ be the inductor current and load current respectively.
So above equation can be written as:

$$x_2 = -\frac{\beta}{c}(i_L - i_r) \quad (3)$$

Let the voltage dropped across inductor be $v_L$ then,

$$v_L = (uV - V_o) = L\frac{di_L}{dt}$$

$$\Rightarrow \quad i_L = \int \frac{uV - V_o}{L} dt$$

So equation (3) can be rewritten as,

$$x_2 = \dot{x}_1 = \frac{\beta}{c}\left(\frac{V_o}{r_L} - \int \frac{uV_i - V_o}{L} dt\right) \quad (4)$$

Hence,

$$\dot{x}_2 = -\frac{1}{LC}x_1 - \frac{1}{r_L C}x_2 - \frac{\beta V}{LC}u + \frac{V_{ref}}{LC} \qquad (5)$$

From equation (2) & (5), the state-space model of Buck Converter system is obtained

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}0 & 1\\ -\frac{1}{LC} & -\frac{1}{r_L C}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}0\\ -\frac{\beta V}{LC}\end{bmatrix}u + \begin{bmatrix}0\\ \frac{V_{ref}}{LC}\end{bmatrix} \quad (6)$$

## III. PI CONTROL

PID control is one of the oldest and classical control technique used for DC-DC converters. It uses one of its families of controllers including P, PD, PI and PID controllers. These different combinations will gives us various ways to regulate dc power supply in these converters. But here we will use only PI in details. Due to the various advantages of PI it is widely used for industrial applications in the area of power electronics. One of the main causes for the use of this classical technique still in industrial applications is easy implementation of tuning method like Ziegler-Nichols tuning procedure by which we can easily optimize proportional,integral and derivative term of this control method needed to achieve a desired closed-loop performance. A proportional integral controller (PI Controller) isa generic control loop feedback mechanism widely used inindustrial control system as well as in research. This approach isoften viewed as simple, reliable, and easy to implement.

## IV. PI CONTROL TUNING USING GOOD GAIN METHOD

The Good Gain method is a simple method which seems to give goodresults on the lab and on simulators. The method is based on experimentson a real or simulated control system, see Figure 2. The procedure describedbelow is for PIcontroller, which is the most commonly used controllerfunction (more common than the P controller and the PID controller).

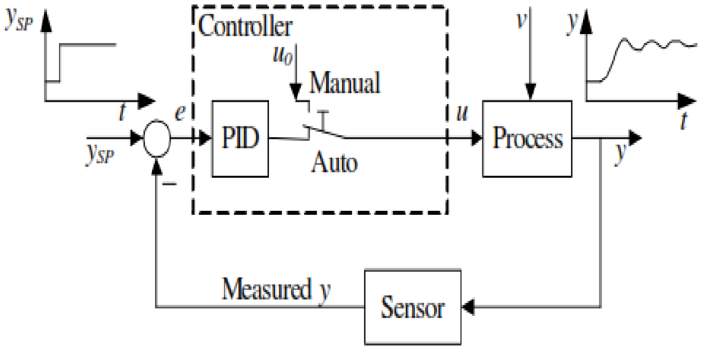


Figure 2: Good Gain method applied to PI Control Tuning to get stable system output

1. Bring the process to or close to the normal or specified operationpoint by adjusting the nominal control signal u(with the controllerin manual mode).
2. Ensure that the controller is a P controller with Kp= 0 (set Ti = ∞and Td= 0). Increase Kpuntil the control loop gets satisfactorystability as seen in the response in the measurement signal after e.g.a step in the set point or in the disturbance (exciting with astep inthe disturbance may be impossible on a real system, but itpossiblein a simulator). If you do not want to start with Kp= 0, you can tryKp= 1 (which is a good initial guess in many cases) and thenincrease or decrease the Kpvalue until you observe a slight overshootbut a well damped response.
3. Set the integraltime Tiequal to
   Ti= 1.5Tou
   Where,Touis the time between the first overshoot and the firstundershoot ofthe step response (a step in the setpoint) with the P controller.
4. Check the stability of the control system by applying a setpoint step.Because of the introduction of the I-term, the loop with the PIcontroller in action will probably have somewhat reduced stabilitythan with the P controller only. If you think that the stability hasbecome too poor, try reducing Kpsomewhat, e.g. reduce it to 80% ofthe original value.

## V. SLIDING MODE CONTROL

In simplest terms, the SM control is a kind of nonlinear control which has been developed primarily for the control of variable structure systems. Technically, it consists of atime-varying state-feedback discontinuous control law that switches at a high frequency from one continuous structure to another according to the present position of the state variables in the state space, the objective being to force the dynamics of the system under control to follow exactly what is desired and pre-determined.

The main advantage of a system with SM control characteristics is that it has guaranteed stability and robustness against parameter uncertainties. Moreover, being a control method that has a high degree of flexibility in its design choices, the SM control method is relatively easy to implement as compared to other nonlinear control methods. Such properties make SM control highly suitable for applications in nonlinear systems, accounting for their wide utilization in industrial applications, e.g., electrical drivers, automotive control, furnace control, etc. In this project, we are concerned with a particular class of variable structure system known as Buck Converter.

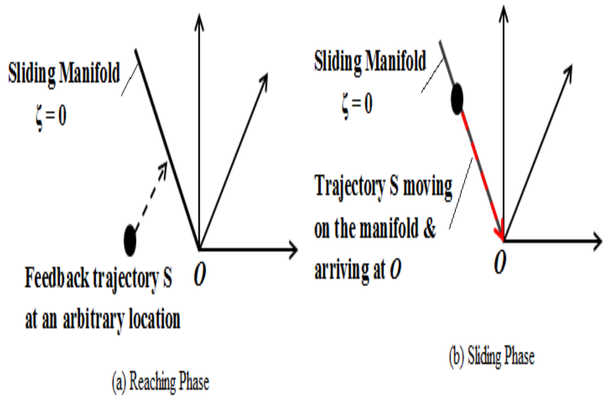


Figure 3: Graphical representation of SM Control Process

Figure 3gives a graphical representation of the trajectory of a system under SM control. The entire SM operation can be divided into two phases. In the first phase (known as reaching phase), regardless of the initial position of the controlled trajectory S, the SM control will force the trajectory toward the sliding manifold (see Figure 3(a)). This is possible through the compliance of the so called hitting condition, which guarantees that, regardless of the initial condition, the controlled trajectory of the system will always be directed toward the sliding manifold.

When the trajectory touches the sliding manifold, the system enters the second phase (known as sliding phase) of the control process and is also said to be in SM operation. The system will then be controlled by a series of infinite switching of its control functions such that the trajectory is maintained on the sliding manifold, and is concurrently directed toward the desired equilibrium point O and finally settling at O (see Figure 3(b)). Importantly, by having a control process that reacts only to the way the trajectory behaves, the trajectory will be immune to the effects of the parametric changes and external disturbances.

## VI. SMC IMPLEMENTATION USING SIGNUM/RELAY FUNCTION

Consider a non-linear time dependent switching-system defined by the equation:

$$\dot{x}(t) = g(x(t)) + \varphi(x(t))u(t) \quad (7)$$

Where, $x(t)$ is the state vector in n dimensional space $R^n$.

$g(.)$ and $\varphi(.)$ are smooth vector fields in the same space.

$u(t)$is the discontinuous control action expressed as

$$u(t) = \begin{cases} U^+ & if\ S(x,t) > 0 \\ U- & if\ S(x,t) < 0 \end{cases} \quad (8)$$

Where, $U^+$ and $U$- are either scalar values or scalar functions of$x(t)$.

$S(x,t)$is the instantaneous feedback tracking trajectory of system and is a predetermined function of the state variable. Typically, for ease of design and implementation, $S(x,t)$is chosen as a linear combination of the weighted values of the state variables, and is given as:

$$S(x,t) = \sum_{i=1}^{m} \alpha_i x_i(t) \quad (9)$$

Where, $\alpha_i$ foe i = 1 to m denotes the set of control parameters known as sliding coefficient

$x_i(t) \in X(t)$

A system with this description is said to exhibit SM property when all the required conditions i.e. hitting condition, existence condition and stability condition are met.

The conventional method of implementing SM Control is based directly on the control low mention in equation 8 which is simply a discontinuous function that is easily realized using a switch relay and equation 9 computes the instantaneous trajectory S(t) is realized through analog or digital computation.

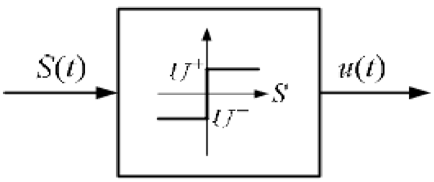


Figure 4: A relay function in SM control

In many application where control law involves only a positive or negative decision i.e. $U^+ = 1$ and $U^- = -1$. The signum function can be used for the relay i.e.

$$u(t) = sgn(S(x,t)) \quad (10)$$

Where the signum function $sgn(.)$ function is defined as

$$u(t) = \begin{cases} 1 & if\ s(x,t) > 0 \\ 0 & if\ s(x,t) = 0 \\ -1 & if\ s(x,t) < 0 \end{cases} \quad (11)$$

For the application where the control involves only digital logic equation 11 is replaced by:

$$u(t) = \begin{cases} 1 & if\ S(x,t) > 0 \\ 0 & if\ S(x,t) \le 0 \end{cases} \quad (12)$$

In general, the implementation of the control using this approach is straightforward and simple. However, the direct implementation of this control law results in systems that are switched at a very high frequency giving an unwanted chattering effect in the system. This makes it unsuitable for some applications which see this as an undesired high-frequency noise. Therefore, for such systems, it is necessary to restrict the range of the operating frequency, for instance, by using a hysteresis function.

## VII. SIMULATION

Table I
Design Specification

| TOPOLOGY | BUCK CONVERTER |
|---|---|
| Inductance (L) | 300µH |
| Capacitance (C) | 5µF |
| Load Resistance ($r_L$) | 3Ω |
| I/P voltage ($V_i$) | 12V |
| Switching frequency ($f_t$) | 50khz |
| Reference voltage ($V_{ref}$) | 2.5V |
| O/P voltage measurement | R1 = 10K & R2 = 10K |

In steady state,

$V_{ref} = V_{mes} = 2.5V$

So by calculation from figure 1

$$V_o = \left(\frac{R_1+R_2}{R_2}\right)V_{ref} = 5\text{v}$$

Simulation results (see figures 6&7) are nearly equal to theoretical value.

In table 1 parameter used for simulation of Buck Converter model (equation 6) is mentioned.

First simulation is done using PI controller. A closed-loop buck converter circuit is illustrated in figure 1. The measurement of the output voltage is realized by 2 resistances R1 and R2. Simulink model of the closed loop converter is shown in figure 5. Initially PI controller is tuned using good gain method and then based on tuning parameter Kp = 10 and Ti = 0.2ms is decided. Figure 6 shows the o/p voltage based on given reference voltage.

Second simulation is done using SM controller. SMC is implemented using SIGNUM function (equation 12). Figure 7 shows the o/p voltage for same condition which used for PI controller.

By comparing results it is justified that use of SM Control would give more accurate result with less fluctuation in o/p voltage than the PI control.

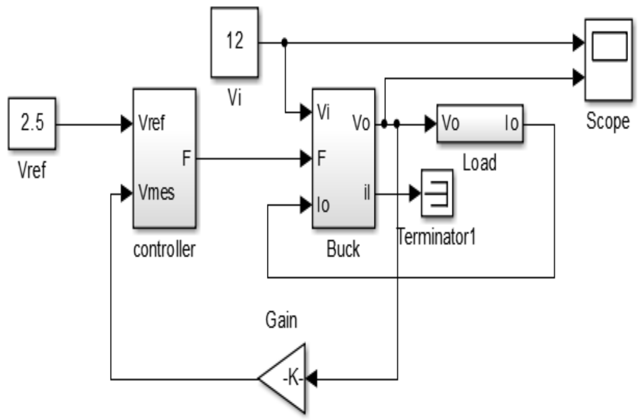


Figure 5: Simulation of voltage control of buck converter

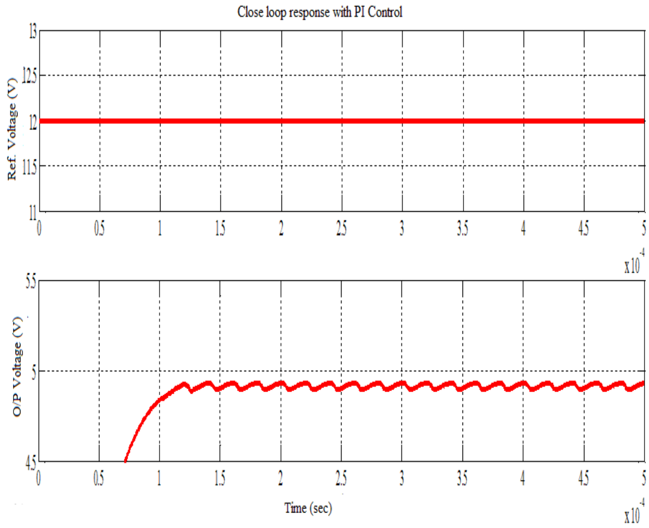


Figure 6: Response of close loop Buck Converter using PI Control

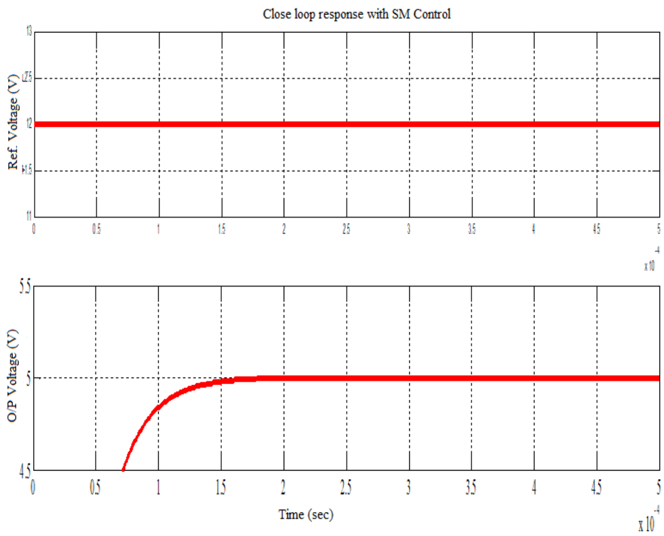


Figure 7: Response of close loop Buck Converter using SM Control

## VIII. CONCLUSION

This paper shows the basic implementation of SM Control for Buck Converter. It is easy and simple in design using time domain analysis. Simulation results compare the design of Buck converter model control using PI Controller and SM controller using signum function. From the result we justified that SM Control gives better performance characteristics than PI Controller. With change in initial condition and load variation fluctuation occurs while using PI Controller in o/p voltage and inductor current which damage the devices such as laptop, mobile etc. From simulation response it is clear that there is no fluctuation when Buck Converter is controlled using SM Controller. Tuning of gain which is necessary in PI Controller is completely solved issue in SM Control design.

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