IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 2, April 2014.

www.ijiset.com

ISSN 2348 - 7968

COMPARISON OF LINEAR AND NON-LINEAR CONTROLLERS

L.Maheswari[1,a*], R.Sorna vadivoo[2,b], S. Vijayalakshmi[3,c]

[a]M.E PED (Second year), Saranathan College of Engg., Trichy, Tamilnadu, India
[b]M.E PED (Second year), Saranathan College of Engg., Trichy, Tamilnadu, India
[c]Assistant Professor/EEE, Saranathan College of Engg., Trichy, Tamilnadu, India

***Abstract:* -- This paper presents the relative difference between the linear and nonlinear controller. The linear controller namely Proportional integral derivate controller (PID) and nonlinear controller called Generalized Proportional Integral (GPI) controller and Sliding mode controller are considered for the response analysis. The transient and dynamic performances of the linear and nonlinear controller in terms of delay time, rise time, peak time, settling time and maximum peak over shoot are analyzed. It is observed that non- linear controller GPI and SMC gives the sturdiness response compared to PID (linear) controller. Therefore, power electronic devices nonlinear controller can be used instead of linear controller.**

***Index Terms*— Buck converter, Proportional Integral Derivative (PID) control system, sliding mode control (SMC), Generalized Proportional Integral (GPI) control system**

I. INTRODUCTION

DC power was obtained earlier from the motor generator set or by converting the AC power using mercury arc rectifiers or thyratrons [11]. The obtained DC power is then converted into a variable DC power by power electronics device known as DC-DC converter. These are having various applications such as traction motor control in electric automobile, trolley cars, marine hoist, Forklift trucks, and mine haulers [9]. The various topology of DC-DC converter are Buck, Boost and Buck-Boost. Among this Buck converter topology is widely used in office equipment, portable machines, and computers and for various control devices [8]. To obtain the desired voltage and current, power conversion devices (controllers) are being used [9,11]. Depending upon the requirement the specific linear or nonlinear controller are selected [10]. Linear controllers like proportional (P), proportional integral (PI), and proportional integral derivate **(**PID) do not offer a good large-signal transient conditions [12]. Therefore, major research has been performed in investigating non-linear controllers namely GPI(Generalized Proportional Integral) and SMC(Sliding Mode Control). The main advantages of these controllers are their ability to react immediately to a transient condition [10]**.** In this work the comparison between non-linear controller robustness (in terms of transient and dynamic response) and linear controller is performed. This paper is organized as follows: In section II, the state space averaging model of the 'buck' converter is presented. Section III, IV and V represents the PID, GPI and SMC control system design procedures respectively. Section VI represents the design details of the control systems in MATLAB SIMULINK. Section VII represents the comparative analysis of PID, GPI and SMC response which is also obtained through MATLAB SIMULINK. Conclusion is given in section VIII.

II. MODELING OF BUCK CONVERTER

The basic circuit of the buck converter with its switching position is shown in fig 1. By using state space averaging method [8], applying the boundary condition u= {1, 0}, equations (1-3) can be obtained.

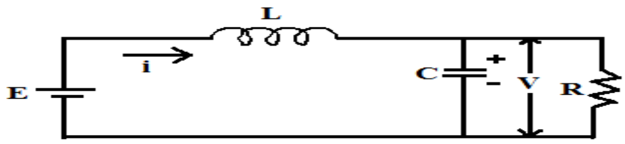


Fig 1(a). Switch Closed at u=1.

By using state space averaging model [6], the following matrix can be obtained

$$A = \begin{pmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{pmatrix} \quad (1)$$

$$B = \begin{pmatrix} \frac{u_{av}}{L} \\ 0 \end{pmatrix} \quad (2)$$

$$C^T = \begin{pmatrix} 0 & 1 \end{pmatrix} \quad (3)$$

u_{av} is represented instead of u. It is the average model of the buck converter. Depending upon the value of u_{av}, the transient and dynamic response of the system will give the robust response. It is in the range of 0-1. In this paper PID, GPI and SMC controller are used and the comparative study between these controller in terms of delay time, rise time, peak time, settling time and maximum peak over shoot are performed.

III. DESIGN OF PID CONTROLLER

In most of the industrial applications PID controllers are being used. The tuning parameters of this controller is obtained through the transfer function of the buck converter by using the average model of the matrix (1)-(3).The transfer function of the PID controller in terms of controller parameters are represented as

$$T.F_{PID}(s) = K_P \left(1 + \frac{1}{T_i s} + T_d s\right) \quad (4)$$

Where K_p is the proportionality constant, which is proportional to the current error value, 'T_i' is the integral time constant and it is proportional to both the magnitude of the error and the duration of the error and 'T_d' is the derivative time constant and it is related to the rate of change of the process error. It is represented in the below block diagram.

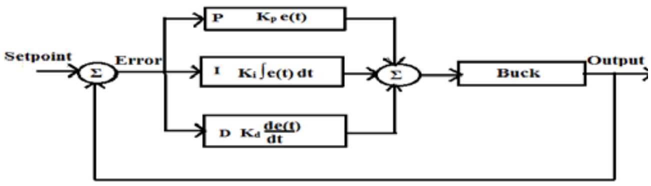


Fig.2 Design of PID controller

IV. DESIGN OF GPI CONTROLLER

GPI is a nonlinear controller and its response is robust when compared to PID controller. Its design step is as follows.

- The Kalman's controllability and Observability of the matrix is initially checked and is represented by the following matrix

$$Q_c = [B, AB] \quad (5)$$

$$Q_0 = [C^T \; A^T C^T] \quad (6)$$

- If the Q_c is nonzero then the system is completely state controllable and it is possible to tranfer the state from any initial state $X(t_0)$ to any other desired state $X(t_d)$ in specified finite time by a control vector U(t) and hence differentially flat.
- Considering this condition, the flat output equation of the buck converter is represented as F=V. The control signal is represented as

$$u_{av} = \frac{LC}{E}\left(\ddot{F} + \frac{1}{RC}\dot{F} + \frac{1}{LC}F\right) \quad (7)$$

The obtained control signal u_{av} is reconstructing in terms of integral estimator of first time derivative of F, if the system is completely state observable. Integrating the equation (19) on both sides we get the variable of $\hat{\dot{F}}$

$$\hat{\dot{F}} = \left(\frac{E}{LC}\right)\int_0^t \left[u_{av}(\tau) - \frac{1}{E}F(\tau)\right] d\tau - \frac{1}{RC}F \quad (8)$$

The desired characteristic polynomial of the controller is chosen as

$$P(s) = (s^2 + 2\zeta\omega_n s + {\omega^2}_n)^2 \quad (9)$$

By comparing the control signal and condition F=V we get,

$$\left.\begin{aligned} K_3 &= 4\zeta\omega_n \\ K_2 &= 4\zeta^2{\omega_n}^2 + 2{\omega_n}^2 \\ K_1 &= 4\zeta{\omega_n}^3 \\ K_0 &= {\omega_n}^4 \end{aligned}\right\} \quad (10)$$

The gain of the GPI controller is positive and roots of this polynomial equation is placed in the left half of the s-plane. Therefore high degree of stability is obtained.

The tuning of stabilization error is very accurate when compared to PID controller.

V. DESIGN OF SMC CONTROLLER

The main advantage of a system with SM control 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. In this paper, voltage mode under CCM operation is considered; therefore voltage error and voltage error dynamic are taken and is represented as

$$x = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} V_{ref} - V_0 \\ \frac{d}{dt}(V_{ref} - V_o) \end{pmatrix} \quad (11)$$

$$\begin{cases} x_1 = V_o - V_{ref} \\ x_2 = \frac{dx_1}{dt} = \frac{dv}{dt} = \frac{i_c}{C} \end{cases} \quad (12)$$

From that assumption, we get the system modeling in the form of $\dot{x} = Ax + Bu + D$ .where u is the control signal for SMC system.

In matrix form

$$A = \begin{bmatrix} 0 & 1 \\ \frac{-1}{Lc} & -\frac{1}{RC} \end{bmatrix}, \text{B=} \begin{bmatrix} 0 \\ \frac{E}{LC} \end{bmatrix}, \ D = \begin{bmatrix} 0 \\ \frac{-V_{ref}}{LC} \end{bmatrix}$$

Like GPI controller SMC is also applicable for large signal transients. Chattering is the main problem in SMC control when compared to GPI control. Now days these controllers are used for advanced power electronic equipment.

VI. SIMULATION OF DESIGN OF CONTROLLERS:

A. *Comparative Simulation result for linear and Non-linear controller*

Specifications of controllers:

PID: L = 12 μ H; C = 100 μ F; R = 2.5 Ω; E = 12 V; f = 400 kHz; K_p = .2; $T_i = 4.097 \times 10^{-6}$;

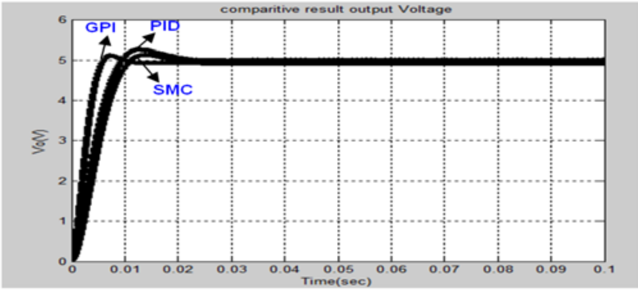
T_d = 2.068×10^{-5}.

GPI: L = 12 μ H; C = 100 μ F; R = 2.5 Ω; E = 12 V; f = 400 kHz; K1 = 9.437×10^{14};

K2 = 2.52×10^{10}; *K3 = 79956.8; K0 =* 1.393×10^{20}; $F_{desired}$=15.

SMC: *f = 400 kHz; L = 12 μ H; C = 100 μ F; R = 2.5 Ω; E = 12 V;*

For this specifications corresponding response is obtained as given below:



VII. COMPARATIVE ANALYSIS OF LINEAR AND NON-LINEAR CONTROLLER

Table 1. Comparison between PID, GPI and SMC controller

Transient response Specification	PID controller	GPI controller	SMC controller
Delay time (t_d)	0.005s	0.002	0.003
Rise time (t_r)	0.008s	0.04	0.05
Peak time (t_p)	0.01	0.0035	0.006
Maximum over shoot (M_p)	2.12%	0%	0.51%
Settling time(t_s)	0.01	0.006	0.008

VIII. CONCLUSION

It is observed that the dynamic response of the buck converter using non- linear controller like GPI controller and SMC controller gives the best response in terms of maximum overshoot, delay time, settling time and steady state error compared to linear controller like PID controller. Further, it is concluded that the GPI controller has a better transient response than a PID control action. Hence GPI controller can be used for advanced power electronics applications like Robotics, velocity control for DC motor etc., SMC controller has many future scope in power electronic applications when compared to linear controller. Hence it is concluded that the non linear controllers GPI and SMC can be used for industrial application provided it has to be available in chip format as a future enhancement. And also it can be concluded that there is a lot of scope available in development of chip formation for non-linear controllers.

REFERENCES

[1] Ahmed M, M. Kuisma, K. Tosla, P. Silventoinen, and O. Pyrhonen, (2003) "Effect of implementing sliding mode control on the dynamic behavior and robustness of switch mode power supply (buck converter)," in Proc. 5th Int. Conf. Power Electron. Drive Syst., vol. 2, pp. 1364-1368, Nov.

[2] Ahmed M., M. Kuisma, K. Tosla, and P. Silventoinen, (2003) "Implementing sliding mode control for buck converter," in Proc. IEEE PESC Rec. , vol. 2, pp. 634-637, Jun.

[3] Bilalovic F., O. Music and A. Sabanovic, (1983) "Buck converter regulator operating in siding mode," in Proc. 7th Int. Conf.PCI, pp. 331-340, Apr.

[4] Edwards C.and S. K. Spurgeron, (1998) Sliding Mode Control: Theory and Applications. London, U.K.: Taylor & Francis

[5] Escobar G., R. Ortega, H. Sira-Ramirez, J. P. Vilain, and I. Zein, (1999) " An experimental comparison of several nonlinear controllers for power converters," IEEE Control Syst. Mag., vol. 19, no. 1, pp. 66-8 2, Feb

[6] Fliess M., R. Marquez, E. Delaleau, and H. Sira-Ramírez, (2002) "Correcteurs proportionnels-intégraux généralisés," ESAIM: Control, Optim. Calculus Variations, vol. 7, pp. 23–41

[7] Forsyth A.J. and S.V. Mollow, (1998) "Modeling and control of dc-dc converters," IEE power engineering journal, vol. 12, no. 5, pp. 229–236, Oct.

[8] Middlebrook R.D. and Cuk, S. (1976) "A general unified approach to modeling switching Converter Power stages," in Proc. IEEE PESC Rec., pp. 18–34,

[9] Mohan N., Undeland, T. M. Robbins, W. P. (2002) Power Electronics: Converters, Applications, and Design, 3rd Bk&Cdr edition, Wiley

[10] Ogata, K, (1997) Modern Control Engineering. Upper Saddle River, NJ: Prentice-Hall, Inc.,

[11] Rashid M. H, (2003), Power Electronics: Circuits, Devices and Applications (3rd Edition), Prentice Hall,

[12] Ravira. V.S. C. j and. Sen, P. C (1997) "Comparative study of proportional integral, sliding mode, and fuzzy logic controllers for power converters," IEEE Trans. Ind. Appl., vol. 33, no. 2, pp. 518–524, Mar./Apr

[13] Sira-Ramírez H. (2003) "Sliding modes, Δ-modulators, and generalized proportional integral control of linear systems," Asian J. Control, vol. 5, no. 4, pp. 467–475, Dec.

[14] Sira-Ramirez, H. (2003) "Sliding mode-Δ modulation control of a "buck converter"," in proc. 42end IEEE Conf. Decision control, vol. 3, pp. 2999-3004, Dec

[15] Sira-Ramirez H. and Ilic, M. (1988) "A geometric approach to the feedback control of switch mode DC-to-DC power supplies," IEEE Trans. Circuits Syst., vol. 35, no. 10, pp. 1291–1298, Oct..

[16] Sira-Ramírez H. and Silva-Ortigoza, R. (2006), Control Design Techniques in Power Electronics Devices. London, U.K.: Springer-Verlag

[17] Venkataramanan R., (1986) Sliding Mode Control of Power Converters, PhD thesis, California Institute of Technology, California

[18] Venkatramanan R., A. Sabanovic, and S. Cuk, (1985) "Sliding mode control of DC-to-DC converters," in Proc. IEEE Conf. IECON, pp. 251-258, 1985.

[19] Tan S. C, Y. M. Lai, C. K. Tse, (2008) "General design issues of sliding-mode controllers in dc-dc converters," IEEE Trans. Industrial Electronics., vol. 55, no. 3, pp. 1160–1174, Mar