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Implementation Of Fuzzy Tuned PID Controller For DC-DC Buck Converter

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Abstract

Number of DC-DC converters seen in modern day electronic gadgets relying on battery power has been increased. The stringent requirements in rise time, settling time, immunity to load and line variations lead to addition of controllers to converters. More works done on applying classic and modern controllers are seen in literature. In this study, the asynchronous buck converter with non-ideal components is taken and both electrical and mathematical representations are considered. Compensator is designed using MATLAB® SISOTOOL which is a graphical user interface to satisfy the phase margin and 0 dB crossover frequency requirements. PID and fuzzy tuned PID controllers are developed for the given system and their performances are compared. Fuzzy tuned PID controller with minimum set of rules is designed for electrical representation of the system and the superiority of such controller is demonstrated.

Keywords: DC-DC converter, Buck converter, Compensator, PID controller, Fuzzy Logic controller.

Introduction

Simple and efficient techniques for controllers are needed for any plant with disturbances. In the case of dc-dc converters, the system is itself a nonlinear in nature and subjected to disturbances and uncertainties (Eker and Torun, 2006). The nonlinear phenomena in DC–DC power converters make their analysis and control difficult (Guesmi*et al.* 2008). Compensators are added in the forward paths of feedback loops to shape the loop gain, such that desired performance is obtained. PI controllers are used to increase the low-frequency loop gain, improve the rejection of low-frequency disturbances and reduce the steady-state error (Erickson, 1999). The design guidelines for the linear averaged feedback controllers of a dc–dc switching converter on a given steady state operating condition are explained in (Erickson, 1999; Dixon, 2001, Su *et al.* 2002). Classical linear techniques for the design of controllers have stability limitations around the operating points (Eker and Torun, 2006; Guesmi *et al.*, 2008; Khaligh and Emadi, 2008). Hence digital and nonlinear stabilizing control methods must be applied to ensure large-signal stability (Khaligh and Emadi, 2008). Fuzzy controllers are nonlinear controllers which do not require exact mathematical model and are well suited to nonlinear time-variant systems. In FLC, the knowledge of the expert operating the plant, in that case converter (Guo *et al.*, 2011) is taken. The FLC determines the operating condition from the measured values and selects the appropriate control actions using the rule base created from the expert knowledge (Sambariya *et al.*, 2009). The other advantages of FLC which favour control of converters are simplicity, ease of design and ease of implementation (Gao *et al.*, 2008, Guo*et al.* 2009, Liu *et al.*, 2009; Samosir and Yatim, 2010; Bouchafaa *et al.*, 2011; Cheng, 2011; Dereli *et al.*, 2011; Messai, 2011). In this study, compensator using GUI in MATLAB to obtain desired phase margin and cross over frequency, PID controller and fuzzy tuned PID controller are developed for the asynchronous buck converter with non ideal components.

DC-DC Buck Converter

A buck converter is a step-down DC to DC converter, a type switched-mode power supply that uses two switches (a transistor and a diode as in case of asynchronous operation), an inductor and a capacitor and the schematic is shown in Figure 1. Even though the simplest way to reduce the voltage of a DC supply is to use a linear regulator, a switched mode controller is used for higher efficiency. The specifications of the converter are given in table 1.

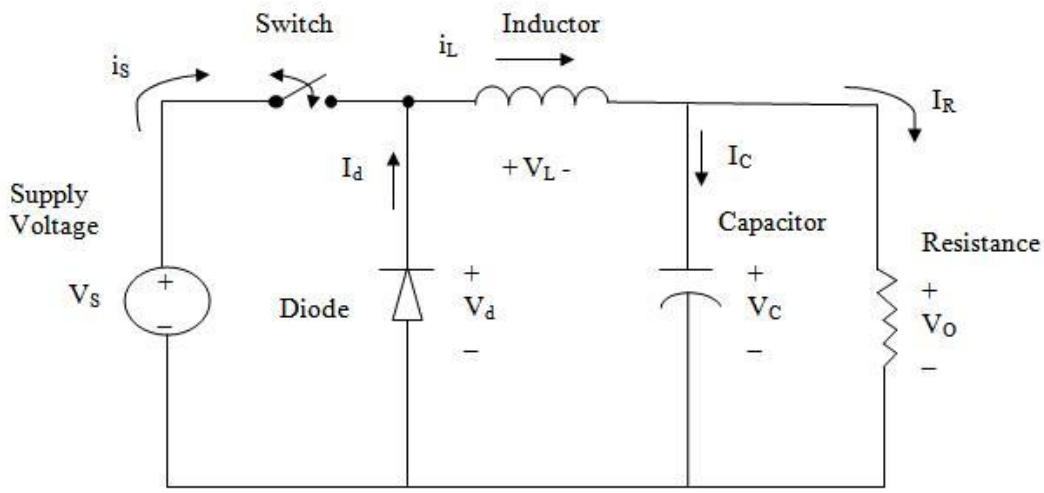

Figure 1: Asynchronous Buck Converter

Table 1: Buck converter parameters

Variable	Parameter	Value
$V_s(V)$	Input voltage	12
$V_{ref}(V)$	Reference output voltage	5
$f_s(kHz)$	Switching frequency	33
$L(mH)$	Magnetizing inductance	1
$R_L(\Omega)$	Inductance internal resistance	0.015
$C(\mu F)$	Output filter capacitance	2200
$R_c(\Omega)$	Capacitance ESR	0.017
$R_o(\Omega)$	Load resistance	1

Substituting the above specifications in the mathematical model of the system (M. M. Abdel and Aziz et.al., 2012), the following transfer functions are obtained.

The control-to-output Transfer Function is given by eq.1.

$$G_{vd}(s) = \frac{200.4s + 5363364}{s^2 + 478.6631s + 453651.42} \quad (1)$$

Compensator

The compensators added in the forward paths of feedback shape the loop gain and helps in achieving the desired response. Fortunately, basic approaches for optimal feedback compensator design could be accomplished quickly and easily in the MATLAB/SIMULINK environment. The "SISOTOOL ('bode')" command in the control system toolbox provides a GUI so that the closed-loop frequency response can be interactively changed by online modification of the pole-zero pattern of the feedback controller. When the desired frequency is obtained, users are also given the corresponding transfer function of the feedback controller in the same interface (Su *et al.*, 2002).

The following points are to be considered while designing the controller.

1. The value of the 0 dB crossover frequency of the closed loop gain should be lower than one third of the switching frequency.
2. The phase margin should be in such a way to meet both the stability and performance requirement.
3. The gain should be high such that the influences of the disturbances would be kept as small as possible.
4. Output voltage steady state error could be eliminated if an integrator is included in the controller.

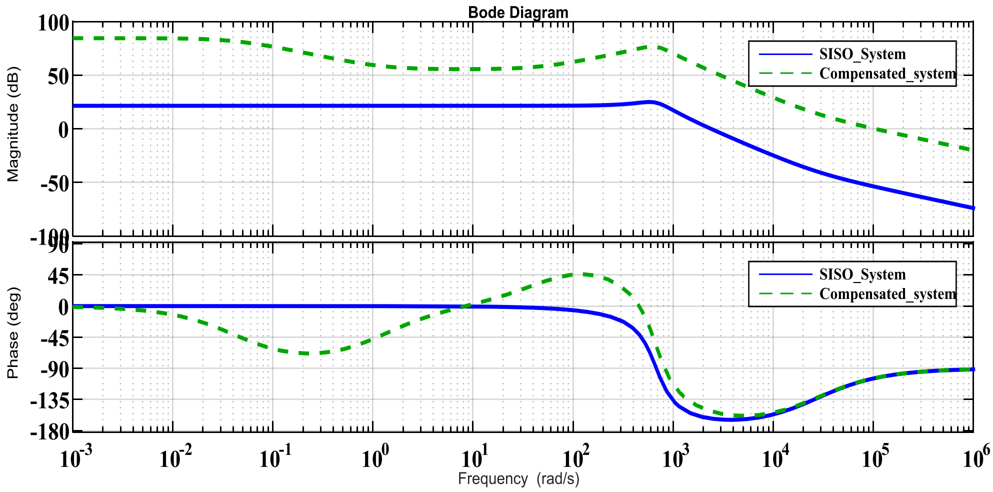

Figure 2: Compensated and un-compensated DC-DC buck converter bode plot

By using above guide lines the controller is designed to give a phase margin of 58.7 degree at 0-dB crossover frequency of about $4.18*10^4$ rad/sec.Without compensator the phase margin is 17.4 degree which is too low.

The transfer function of the compensator is given in eq.2.

$$G_c(s) = 500 * \frac{(s+1.24)(s+50)}{(s+500)(s+0.0436)} \qquad (2)$$

bode plots of the system before and after adding compensator are shown in Figure 2.

PID Controller

PID controller is a device which does proportional action, integral action and derivative action on the error signal which is the difference between the real and desired outputs. The parameters of the PID controller can be obtained by various tuning algorithms (M.Namnabat, 2007). In this study, they are obtained by using Ziegler-Nichols method. The obtained controller parameters are K_p = 320, K_i = 30 and K_d = 0.1.

Fuzzy Tuned PID controller for DC-DC converters

Work related to FLC for dc-dc converters are extensively available in the literature (Corcau and Stoenescu, 2007; Elmas *et. al.*, 2009; Guesmi *et al.*, 2008). A fuzzy controller contains four main components namely, fuzzification which converts the crisp input to fuzzy inputs suitable for processing by the fuzzy inference engine, a rule base containing the expert in dc-dc converters knowledge, the inference mechanism that evaluates which contain control rules are relevant in the current situation and the defuzzification interface which converts fuzzy outputs to crisp outputs. Designing of fuzzy controllers involves choosing the fuzzy controller's inputs and outputs and choosing the preprocessing for the controller inputs and post processing for the controller outputs.

The fuzzy tuned PID controller is shown as a block diagram in Figure 3 where *r(t)* is reference input, the parameters of PID controller are FLC output and *y(t)* is the dc-dc converter output.

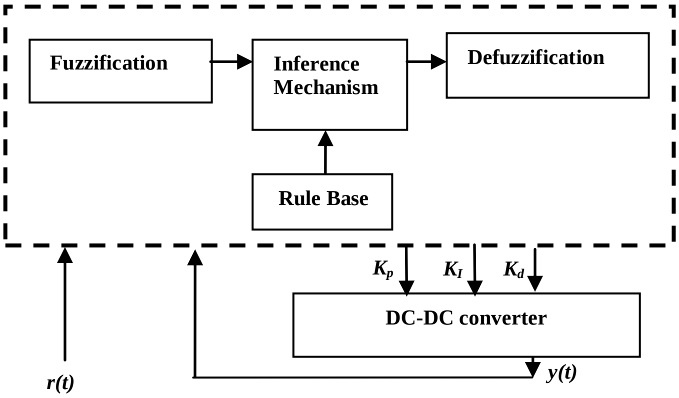

Figure 3: Basic block diagram of a fuzzy tuned PID controller

Performance Comparison

The output voltages of the converter using different controllers are shown in Figure 5. Each controller's behavior is compared with open loop and is shown in the same plot. Table 3 shows the fuzzy rules implemented in the fuzzy tuned PID controller. The bar chart shown in Figure 4 gives the comparison of behavior of the system for all three types of controllers in terms of transient performance parameters.

Table 3: Fuzzy Rules Table

Error	**Change in Error**	**NS**	**ZE**	**PS**
	NS	NS	NS	ZE
	ZE	ZE	ZE	PS
	PS	ZE	PS	PS

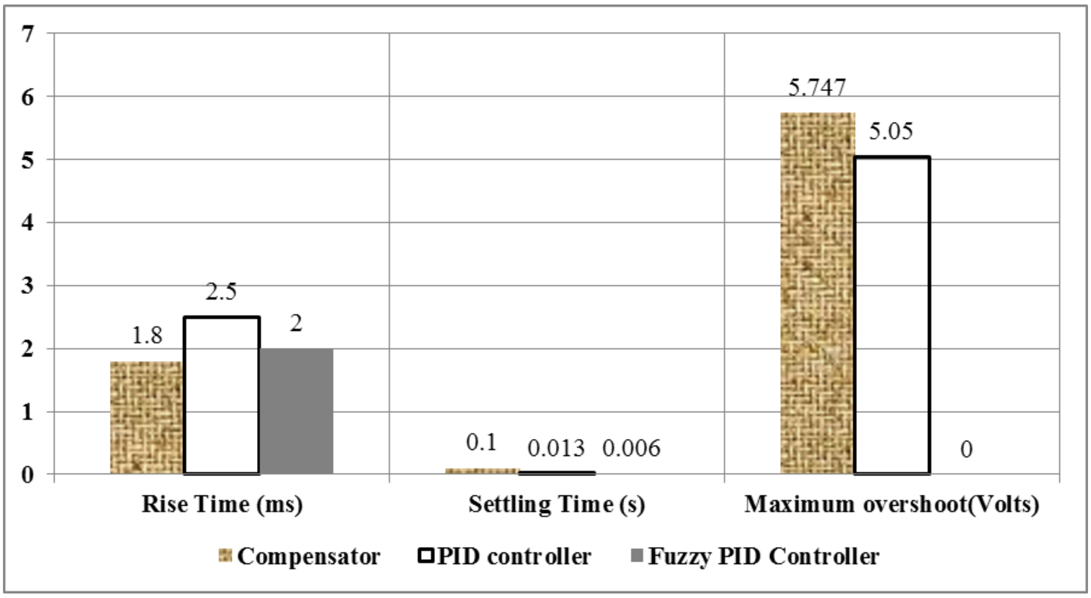

Figure 4: Performance Comparison of Various Controllers

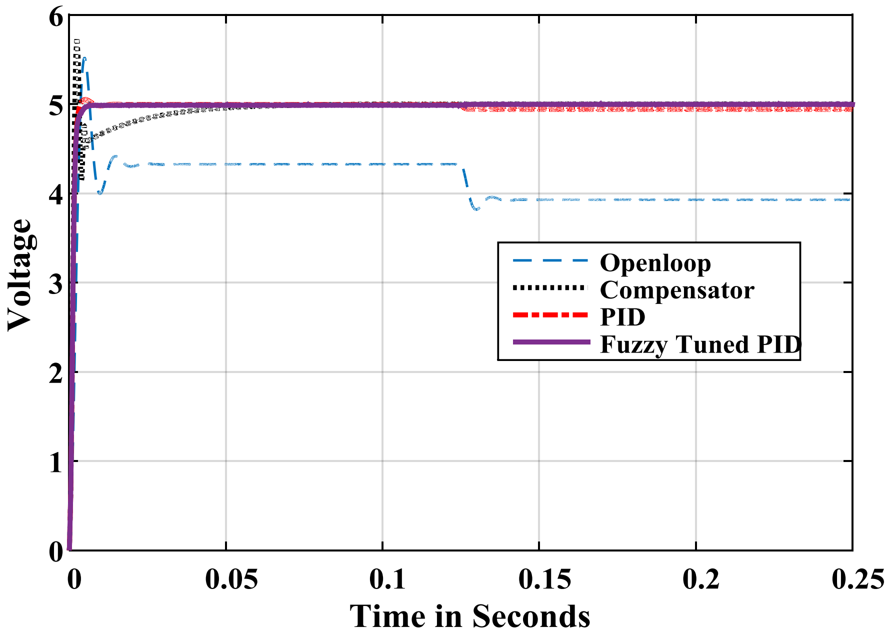

Figure 5: Closed loop response of different controllers

Performance of Controllers under Load Variations

In this section the robustness of the controller is observed and it is determined by the steady state output irrespective of load variations. The load current is varied from designed value of 5A to 7.5A at 0.15 seconds and then to 5A at 0.3 seconds for every0.5seconds. Figure 6 shows the behavior of the controllers under load transients. From the graph, it can be inferred that fuzzy logic controller is able to outperform well under transient conditions.

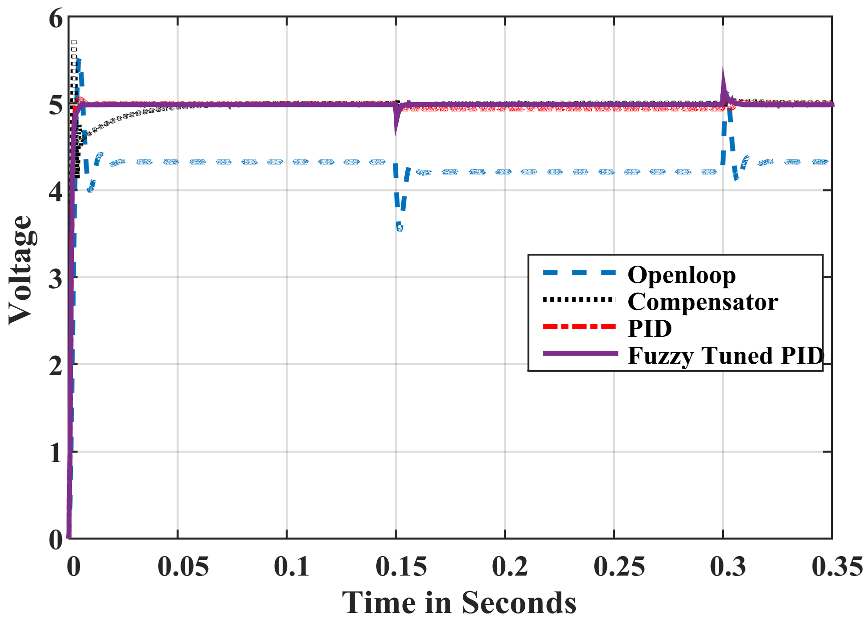

Figure 6: Output voltage response of different controllers under load transients

The bar chart shown in Figure 7 reveals that fuzzy tuned PID controller is able to perform satisfactorily at all operating points.

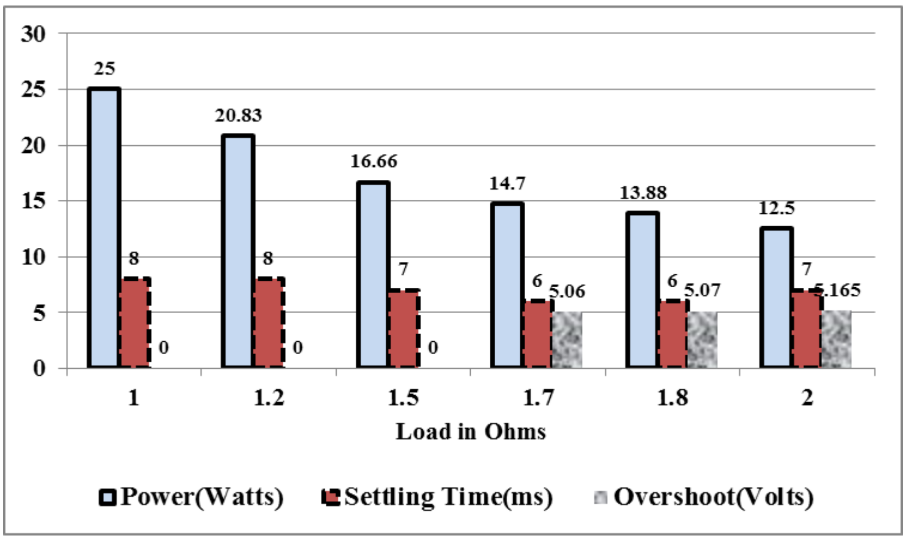

Figure 7: Performance Parameters of Vout for various load power

Conclusion

In this paper a Buck converter is analyzed in detail. The mathematical and electrical modeling with non-ideal conditions is taken into study. MATLAB based analysis is shown in detail. Compensator design using SISO tool of MATLAB is explained and the compensator with required parameters are tuned graphically. PID and fuzzy tuned PID controllers are developed using MATLAB/SIMULINK. The advantage of Fuzzy Logic tuned PID Controller over conventional PID controller is also shown.

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