2015 International Symposium on Nonlinear Theory and its Applications
NOLTA2015, Kowloon, Hong Kong, China, December 1-4, 2015

Dynamic Optimization of DC-DC Converters Based on a Nonlinear PID Controller with Tracking Differentiator

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Abstract– Considering that traditional PID controller has the problem for amplifying the noise when extracting the differential of signal, the tracking-differentiator is adopted to construct the nonlinear PID controller. The theoretical analysis and simulation are done to study the influence of the tracking-differentiator to the control process. Then the designed nonlinear PID controller is adopted into the controlling part of DC-DC converters to optimize the dynamic property. A boost converter is taken as an example, compared with traditional PID controller, the simulation shows that the nonlinear PID controller can control the system more quickly and smoothly, realizing the dynamic optimization of the boost converter.

1. Introduction

As PID control is simple, effective and robust to modeling errors, it is widely used in DC-DC applications.

The traditional PID controller gets the error between the actual value and the set value as the input, and constructs the present error(P), accumulation of past errors(I) and prediction of future errors(D) in a linear way as the controlled variable. But in practical engineering, it is hardly to extract the continuous and differential signal from the signals discontinuously or with random noise for the traditional PID controller. To solve the problems, the nonlinear tracking–differentiator(TD) was first presented in [1].

Following, the general type of TD is given in[2], and the strict proof for signal-tracking is also presented. In recent years, many experts have done some researches on TD. In [3], the system types that can be used as TD have been discussed. The [4-8] raised several new types of TD to solve practical control problems. And the TD is applied into brushless dc motor servo system in [9], which get a good control effect.

In this paper, the nonlinear tracking–differentiator is adopted to improve the traditional PID control, then the revised nonlinear PID controller is used in DC-DC converters to optimize the dynamic property.

2. The construction of TD

2.1. The extraction of differential signal

The form of the classic differentiator[10] is:

$$y = \omega(s)v = \frac{s}{\tau s+1}v = \frac{1}{\tau}(1-\frac{1}{\tau s+1})v \tag{1}$$

$$y(t) \approx \frac{1}{\tau}(v(t)-v(t-\tau)) = \dot{v}(t) \tag{2}$$

When the input signal $v(t)$ is along with the random noise signal $n(t)$, the $n(t)$ will be approximate to zero after $v(t-\tau)$ [11].

$$y(t) \approx \frac{v(t)-v(t-\tau)}{\tau} + \frac{n(t)}{\tau} \tag{3}$$

The τ is smaller, the effect of noise amplification is more serious.

If $\dot{v}(t) \approx \frac{v(t-\tau_2)-v(t-\tau_1)}{\tau_2-\tau_1}$ is adopted, the noise amplification effect will be reduced:

$$y = \frac{1}{\tau_2-\tau_1}(\frac{1}{\tau_1 s+1}-\frac{1}{\tau_2 s+1})v \tag{4}$$

The realization of the differential function depends on tracking the input signal "as soon as possible". And to track the input signal "at the soonest "[12], the tracking-differentiator is introduced.

2.2. Tracking-differentiator(TD)

TD is the development of the traditional differentiator. It achieves a smooth approximation for the generalized derivative of the input signal by nonlinear function. Tracking differentiator is able to extract the differential signal from the discontinuous signals and the signals with noise, it has good filter performance[13], reasonable transient process and superior frequency response[14].

The block diagram of TD is shown below:

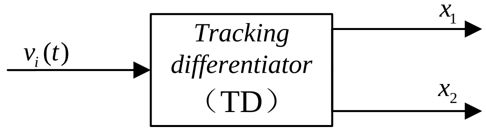

Fig. 1 The block diagram of TD

There will be two output signals x_1 and x_2 for the TD. x_1 tracks the input signal $v_i(t)$, and $\dot{x}_1 = x_2$, x_2 is the approximate differential of $v_i(t)$. So, x_1 realizes the arrangement of the transition to $v_i(t)$, and x_2 realizes the extraction of the differential signal.

Tracking differentiator has different types as the nonlinear function used is different. In the paper, *sat* function is adopted to construct the nonlinear TD.

2.3. The tracking-differentiator based on *sat* function (STD)

The *sat* function is:

$$sat(A,\delta)=\begin{cases} sign(A), |A|>\delta, \delta>0 \\ \dfrac{A}{\delta}, |A|\le\delta, \delta>0 \end{cases} \tag{5}$$

The tracking-differentiator based on *sat* function:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -rsat(x_1 - v_i(t) + \dfrac{x_2|x_2|}{2r}, \delta) \end{cases} \tag{6}$$

STD is derived by the time optimal control, it is simple and there are only two variables. In (6), r affects the tracking velocity, the bigger r is, the time of transient process is smaller. But a too big r will result in the oscillation of the system. δ is the size of the linear range.

The STD model is shown in Fig. 2.

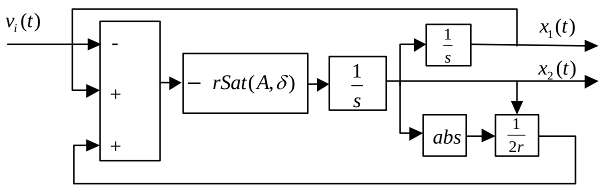

Fig. 2 The structure of STD model

1) The output x_1 when the input is constant signal with amplitude 10

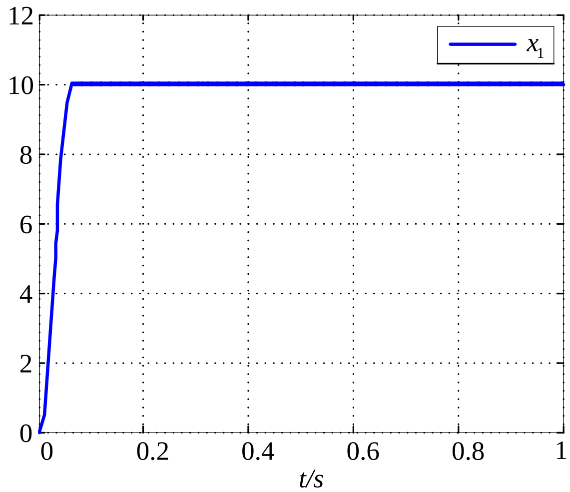

Fig.3 The output waveform with a constant input signal

2) The output x_1 and x_2 when the input is square wave

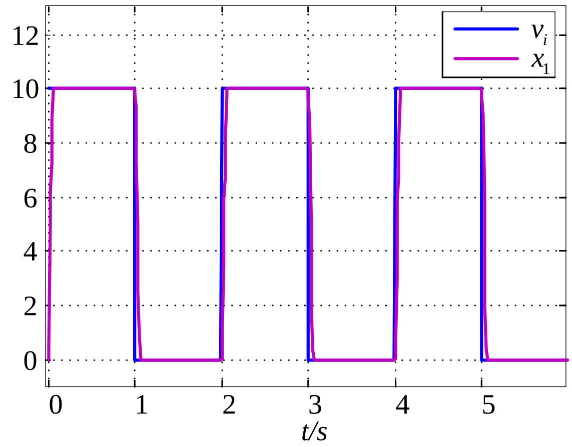

Fig. 4 The output x_1 with a square wave input signal

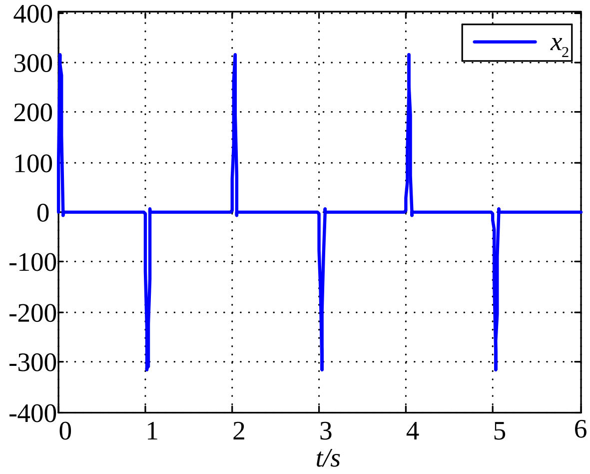

Fig. 5 The output x_2 with a square wave input signal

3) The output x_1 when the input is sine wave(amplitude 10) with high frequency white noise(amplitude 0.8)

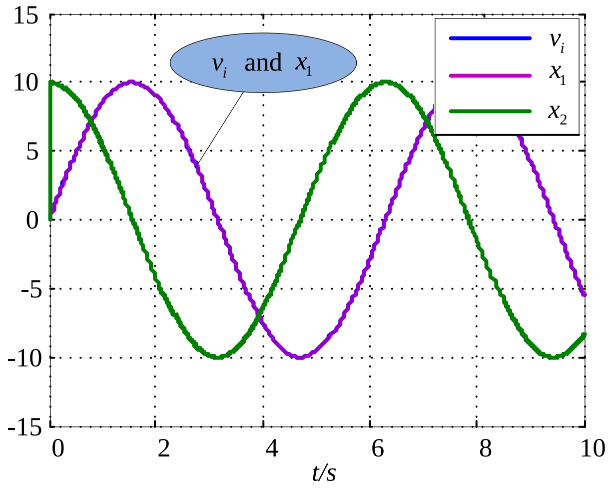

Fig. 6 The output waveform with a sine wave signal

From the simulation results, no matter what kind of input signal is, the output x_1 can track the input signal quickly without oscillation. Moreover, there is almost no phase shift between the output x_1 and input $v_i(t)$, the differential signal x_2 is accurate and without noise.

When the STD is placed at the input terminal, the output signal can achieve a smooth approximation for the input signal, which avoid the unreasonable error generated by the sudden change when input signal goes from 0 to the demand value at the beginning time. Meanwhile the overshoot is reduced and the STD also has filtering action on input signal.

When the STD is placed at the output terminal, the differential signal can be extracted without noise, and the influence of noise and disturbance on the output signal can be eliminated by the filtering action.

3. The simulation for the application of the nonlinear PID controller

The paper takes boost converter as an example. The nonlinear PID controller constructed by STD is adopted in the control loop, and the comparison with traditional PID control is given.

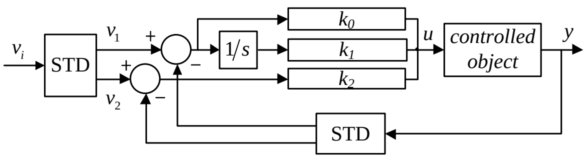

Fig. 7 The nonlinear PID controller constructed by STD

The parameters of the boost converter is shown below:

Table.1 The parameters of the main circuit for boost converter

Input Voltage	Output Voltage	Switching Frequency
25V-30V	50V	6kHz
Inductance	Load resistor	Capacitance
0.4 mH	20Ω-15Ω	440 uF

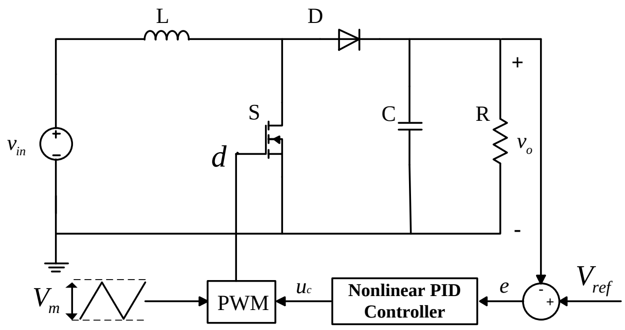

Fig. 8 Boost converter with nonlinear PID control

a. The comparison of the two control methods when the input with high frequency white noise(amplitude 0.8)

For the traditional PID controller, a group of optimal parameters is obtained by the parameter setting method[15] based on frequency domain: k_p=0.005, k_i=4, k_d=0.00004.

For the nonlinear PID controller, let the r=1000000, δ=0.02, k_0=0.3, k_1=4, k_2=0.0001.

The output voltage waveforms for the two controller are shown in Fig. 9.

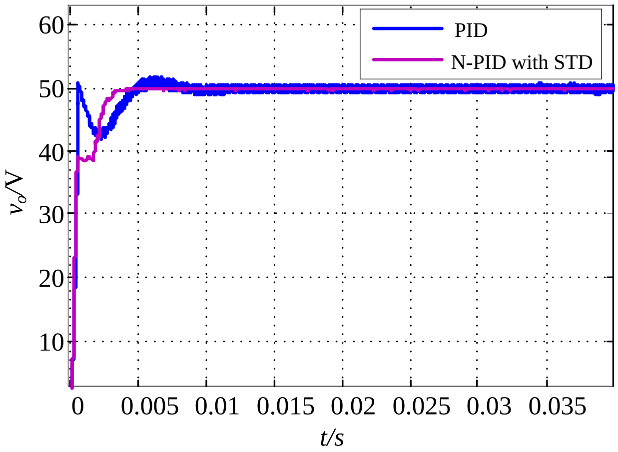

Fig. 9 The output voltage waveforms for the two control methods

The dynamic performance of the two control methods is shown in Table. 2.

Table. 2 The dynamic performance of the two controllers for the output voltage

Control Method	Overshoot (%)	Accommodation Time (ms)	voltage ripple (%)
Traditional PID control	3	10	2
Nonlinear PID control	0	4	0.4

Compared with Traditional PID control, it can be seen that the time output voltage achieves stable and the overshoot is less for nonlinear PID control, and it also has a better filtering effect.

b. The comparison of the two control methods for voltage sudden change and load sudden change

Let input voltage changes suddenly at 0.04s from 25V to 30V, the output voltage waveforms for the two controller are shown in Fig. 10.

Let load resistance changes suddenly at 0.04s from 20Ω to 15Ω, the output voltage waveforms for the two controller are shown in Fig. 11.

The dynamic performance of the two control methods is shown in Table. 3.

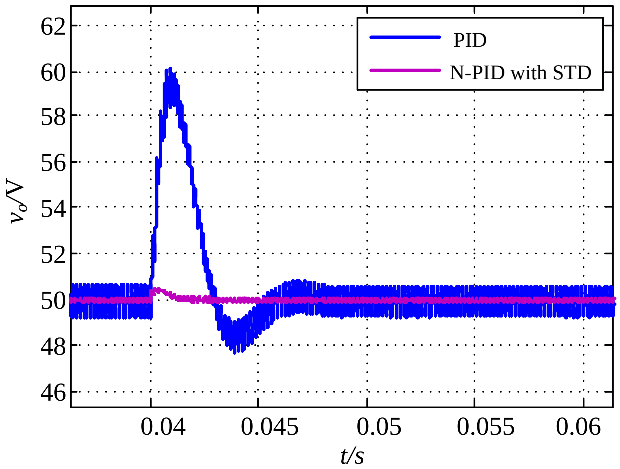

Fig. 10 The output voltage waveforms for voltage sudden change

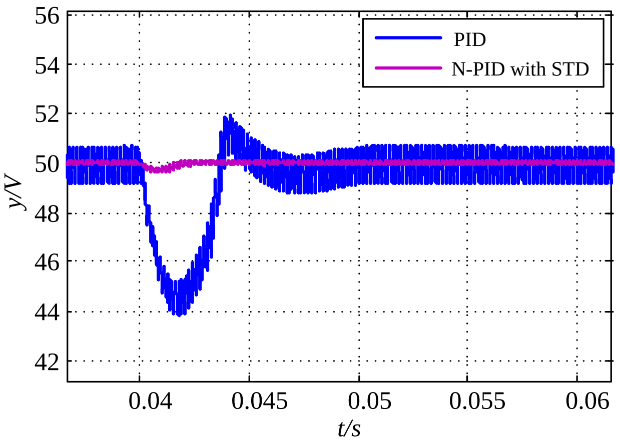

Fig. 11 The output voltage waveforms for load sudden change

Table. 3 The dynamic performance of the two controllers for the voltage and load sudden change

Control Method	voltage sudden change		load sudden change	
	Overshoot (%)	Accommodation Time (ms)	Overshoot (%)	Accommodation Time (ms)
Traditional PID control	5.6	6	0.9	10
Nonlinear PID control	1	2	0	2

Compared with Traditional PID control, the output voltage with nonlinear PID control has a better dynamic performance, which effectively improves the robustness and adaptability of the converter.

4. Conclusions

Aiming at the disadvantages of traditional PID controller, the nonlinear PID controller with tracking differentiator is constructed. And it is applied into a boost converter. By comparing the modulation process of nonlinear PID control and traditional PID control under the voltage and the load sudden change, it is shown that the nonlinear PID controller can realize non-error adjustment faster and at the same time reduce the overshoot. Also, it has better modulation and anti-interference effect for the external disturbances and noise. The nonlinear PID controller has better applicability and control performance in the application of DC-DC converters, which provides a new choice for the control methods of the power converters.

References

[1] Han Jingqing. “The control law of Relay with PID,” The National convention of control theory and application (xi’an), 1989.

[2] Han Jingqing, Wang Wei. “Nonlinear tracking-differentiator,” J. Sys. Sci.& Math. Scis. 14(2), 177–183(1994).

[3] Xue Wenchao, Huang Yi, Yang Xiaoxia, What Kinds of System Can Be Used as Tracking-Differentiator, Proceedings of the 29th Chinese Control Conference, 2010.

[4] Wang Jiuhe, Zhang Jinlong, Van Jian, A New Second Order Nonlinear Tracking Differentiator and Application, 2010 International Conference On Computer Design And Applications, 2010.

[5] Lei Li, Xinchun Jia, Xiaobo Chi, Wei Yan, An improved tracking differentiator capable of compensating phase lag, Automatic Control and Artificial Intelligence (ACAI 2012), 2012.

[6] Shi Yongli, Hou Chaozhen. “Design of improved nonlinear tracking differentiator,” Control and decision, 2008.

[7] Ge Lianzheng, Chen Jian, Li Ruifeng. “Design of an improved tracking differentiator,” Journal of Jilin University (Engineering and Technology Edition), 2011.

[8] Yong Li, A Complementary form of the Discrete Tracking-Differentiator, 2010 International Conference on Measuring Technology and Mechatronics Automation, 2011.

[9] Ben Guo, Liying Hu, Yang Bai, A Nonlinear PID Controller with Tracking Differentiator Applying in BLDCM Servo System, 2012 IEEE 7th International Power Electronics and Motion Control Conference - ECCE Asia, 2012.

[10] Han Jingqing. “From PID to Active Disturbance Rejection Control,” IEEE Trans. Ind. Electron., 56(3), 900–906(2009).

[11] Han Jingqing. Active Disturbance Rejection Control Technique-the technique for estimating and compensating the uncertainties, Beijing: National Defence Industry Press, 2008.

[12] Han Jingqing. “Auto disturbances rejection control technique,” Frontier Science, 2007, 1(1): 24 -31.

[13] Wu Liqiang, LIN Hao, HAN Jingqing. “Study of Tracking Differentiator on Filtering,” JOURNAL OF SYSTEM SIMULATION, 2004.

[14] Li Qiao, Wu Jie. “Nolinear PID control in DC -DC Converter,” Journal of south China university of technology, 2004.

[15] Wang Yagang, Dai Zixiang, Shao Huihe. “The Self—Tuning PID Controller Based on Frequency Domain Recognition,” Automation instrument, 2000.