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Research on One-Cycle Control for Switching Converters

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Abstract **- A new nonlinear control technique that improved one-cycle control technique is proposed. It is based on the theory of one-cycle control technique. One-cycle control technique is firmness for power disturbance, but it is infirmness for load disturbance. The improved one-cycle technique overcomes the shortcoming of one-cycle control technique. It is strong to reject power source and load disturbance. Simulations with a buck converter have demonstrated the feasibility of the new control technique.**

Index Terms - One-cycle control. Nonlinear control. DC/DC switching converters.

I. INTRODUCTION

Switching converters are pulsed nonlinear dynamic systems, so systems under proper pulsed nonlinear control should be more robust, have faster dynamic response, and provide better rejection of power source and load disturbance than the same systems under linear feedback control.

It is not satisfaction at DC/DC converters by conventional feedback control. Conventional feedback control is slow to respond the disturbance of power source and a large number of switching cycles is required before the steady-state is regained. Current-mode control is proposed in [1][2], but an artificial ramp is generally applied in order to eliminate the oscillation that occurs when the duty-ratio is greater than or equal to 0.5. If the artificial ramp is precision, the system will reject the power source disturbance in one cycle. In general, the falling slope of the inductor current of a switching converter is a function of some dynamic states; therefore, it is not possible for the artificial ramp to match the falling slope of the inductor current in a transient. Due to this mismatch, current-mode control is unable to reject the power source disturbance in one switching cycle. In a feedforward buck converter, the power source voltage directly controls the duty-ratio before the output voltage error occurs, but this scheme is not able to accurately reject the power source disturbance. ASDTIC converters are introduced in [3]. This method is similar to the continuous-time linear integral control, which yields a zero steady-state error but a non-zero dynamic error. In addition, it is not stable when the duty-ratio is greater than of equal to 0.5. Sliding-mode control belong to a nonlinear control method is proposed in [4]. This method needs many switching cycles; and the switching frequency is variable. A new nonlinear control technique, one-cycle control is proposed in [5][6]. It takes advantage of the pulsed and nonlinear nature of switching converters and achieves instantaneous dynamic control of the average value of a switched variable; more specifically it takes only one switching cycle for the average value of the switched variable to reach a new steady- state after a transient. There is no steady-state error or dynamic error between the control reference and the average value of the switched variable. This technique provides fast dynamic response, excellent power source disturbance rejection, robust performance, and automatic switching error correction. Though one-cycle control has so many advantages, it is infirmness for load disturbance. State-feedback is used in [7]. This method has excellent load disturbance rejection, but is infirmness for power source disturbance. Function control is proposed in [8][9]. It is better to reject power source and load disturbance, but the response is slow, easy to be disturbed, performance ratio to price low, control current complex.

This paper proposed a new technique, improved one-cycle control technique. It based on one-cycle control and belongs to nonlinear control technique. This method is excellent for power source and load disturbance rejection. It is made of one-cycle control converter and PI adjuster. It has many advantages, e.g., excellent robust performance, fast dynamic response, and so on.. Simulations with a buck converter have demonstrated the feasibility of the new control technique. In addition this technique can be used in others switching converters.

II. ONE-CYCLE CONTROL CONCEPT

A buck converter is shown in Fig. 1. The dc power source voltage is v_g and the switch S operated with a constant frequency f_s. When the MOSFET is on , the diode is off, and the diode-voltage v_s equals the power source voltage v_g. When the MOSFET is off, the diode is on (in CCM), and the diode-voltage v_s is zero. The power source voltage is chopped by the switch resulting in a switching variable v_s. After v_s pass by LC low-pass filter, on the C is the output dc voltage.

Close observation of the switched variable leads to a simple fact. The output voltage of the buck converter is the average value of the switched variable.

$$V_s = \frac{1}{T_s}\int_0^{T_s} v_s dt = \frac{1}{T_s}\int_0^{dT_s} v_g dt . \qquad (1)$$

One-cycle control theory of buck converter is shown in Fig. 2.

A constant frequency clock turns on the MOSFET at the beginning of each seitching period. The diode-voltage isintegrated and compared with a control reference, the comparator changes its state. As a result, the MOSFET is turned off and the integrator is reset to zero. The power source voltage, diode-voltage, diode average voltage, reference control voltage are shown in Fig. 3 and Fig. 4.

With this control scheme, the duty-ratio d is determined by

$$\frac{1}{T_s}\int_0^{dT_s} v_g dt = v_{ref}. \qquad (2)$$

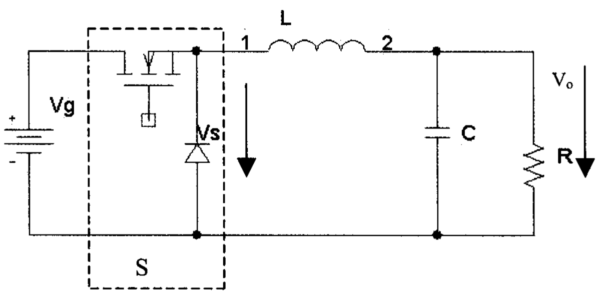

Fig. 1. Buck converter

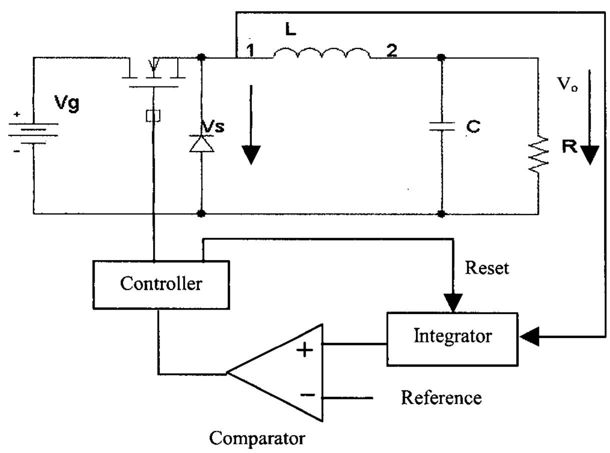

Fig. 2. One-cycle control of buck converter

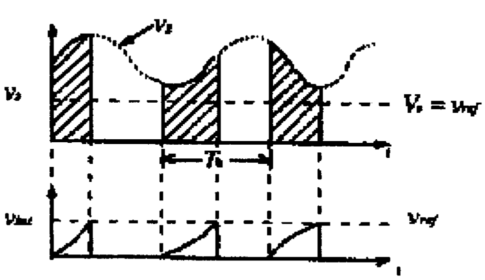

Fig. 3. Constant control reference

From the expressions (2) we know the duty-ratio d is nonlinear function of the power source voltage and the control reference. With this nonlinear control, the output voltage of the buck converter becomes a linear function of the control reference independent of the power source voltage,

$$v_o = \frac{v_{ref}}{1+\frac{L}{R}S+LCS^2}. \qquad (3)$$

III. ONE-CYCLE CONTROL THEORY

One-cycle control theory is shown in Fig. 5, operating waveforms of Fig. 5 are shown in Fig. 6.

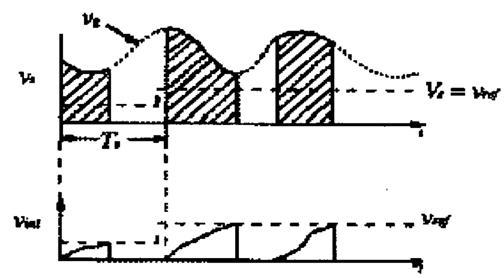

Fig. 4. Variable control reference

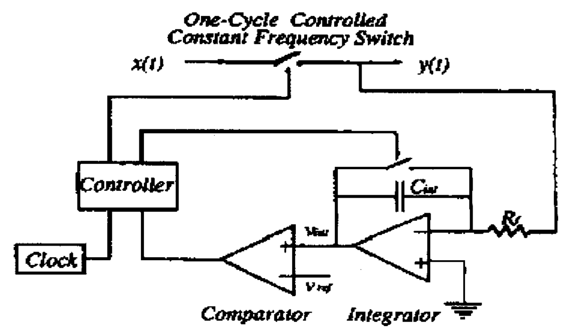

Fig. 5. The theory of one-cycle control

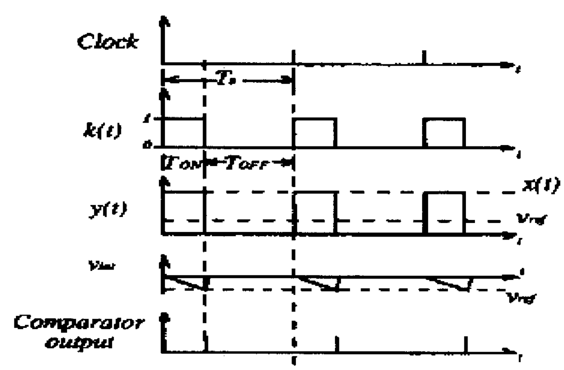

Fig. 6. The waveform of one-cycle control

The switch function is

$$k(t)=\begin{cases}1 & 0<t<T_{ON}\\ 0 & T_{ON}<t<T_s\end{cases}. \quad (4)$$

In each cycle, the switch is on for a time duration T_{ON} and is off for a time duration T_{OFF}, where $T_{ON}+T_{OFF}=T_s$, the duty-ratio $d=T_{ON}/T_s$. From Fig. 5 and (4) we know

$$y(t)=k(t)x(t). \quad (5)$$

The average of the switched variable is

$$y(t)=\frac{1}{T_s}\int_0^{T_{ON}}x(t)dt\approx x(t)d(t). \quad (6)$$

If the duty-ratio of switch is modulated such that the integration of the switched variable at the switch output is exactly equal to the integration of the control reference in each cycle, i.e.

$$\int_0^{T_{ON}}x(t)dt=\int_0^{T_s}v_{ref}(t)dt. \quad (7)$$

then

$$y(t)=\frac{1}{T_s}\int_0^{T_{ON}}x(t)dt=\frac{1}{T_s}\int_0^{T_s}v_{ref}dt=v_{ref}(t). \quad (8)$$

With one-cycle control, the effective output signal of the switch is

$$y(t)=v_{ref}(t). \quad (9)$$

The key component of one-cycle control technique is the integrator and the resetter. The integration starts the moment when the switch is turned on by the fix frequency clock pulse. The integration value,

$$v_{\text{int}}=k\int_0^t x(t)dt \quad k \text{ is constant}. \quad (10)$$

When the integration value reaches the control reference, the controller sends a command to the switch to it from the on state to the off state. The duty-ratio of the present cycle is determined by the following equation:

$$k\int_0^{dT_s}x(t)dt=v_{ref}(t). \quad (11)$$

The average value of the switched variable at the switch output is guaranteed to be

$$y(t)=\frac{1}{T_s}\int_0^{dT_s}x(t)dt=\frac{1}{kT_s}v_{ref}(t). \quad (12)$$

The concept and theory of one-cycle control are introduced in brief at front. please reference [6][10] about the detailed concept and theory of one-cycle control.

IV. IMPROVED ONE-CYCLE CONTROL TECHNIQUE

Though one-cycle control is excellent for rejection the power source disturbance, it is infirmness for load disturbance. The paper proposes a new control technique, improved one-cycle control technique that can overcome this shortcoming. The new control technique on buck current theory is shown in Fig. 7. The main difference with one-cycle control is that the voltage feedback is joined and the error of output voltage relative to control reference operated by PI adjuster and then give the comparator in the new technique. The output of PI adjuster is constant at stable state.

The improved one-cycle control current is equal to one-cycle control current when power source having a disturbance. The adjusting process is same to one-cycle control. According to the one-cycle control the adjusting is completed in one switching cycle to reject the power source disturbance. So it is excellent to power source disturbance rejection.

The error signal that output voltage with reference will change at once when load having a disturbance. The error signal is operated by PI adjuster and then give it to comparator. Due to the reference of comparator changed, the duty-ratio will change at once. This process is same to the one-cycle control that the control reference is variable. When the output achieves to stable state, the output of PI adjuster backs to the value that the output of PI adjuster at stable state. According to before detailed, the new technique can rejects the load disturbance.

V. THE SIMULATION RESULT OF IMPROVED ONE-CYCLE CONTROL

The improved one-cycle control technique is demonstrated by computer simulation. The operating condition for the simulation is T_s=20μs, L=0.48mH, C=30μF, R=25Ω.

First the simulation is on about power source disturbance. When the power source has a disturbance, from 10V to 15V, the power source voltage and the output voltage are shown in Fig. 8 and Fig. 9, the Fig.8 is used one-cycle control technique, the Fig.9 is used improved one-cycle control technique. From the Fig.8 and Fig.9 we can know that the output voltage do not change almost when the power source having a disturbance. So the two techniques are excellent to reject the power disturbance.

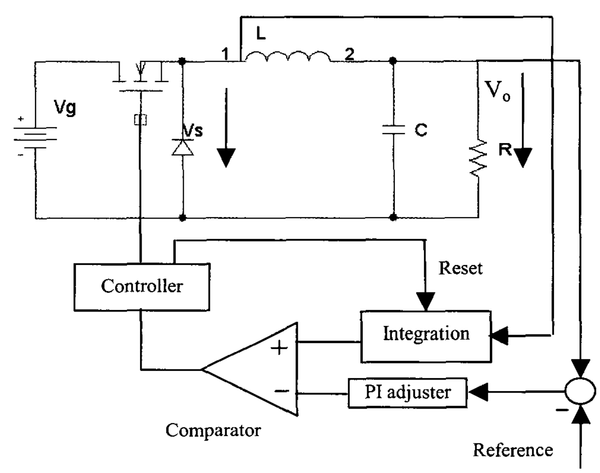

Fig. 7. The buck current of improved one-cycle control

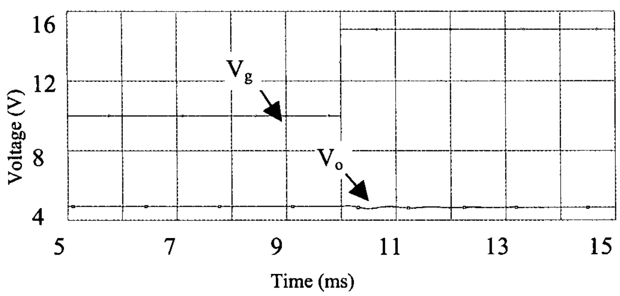

Fig.8. The power source and output voltage using one-cycle control

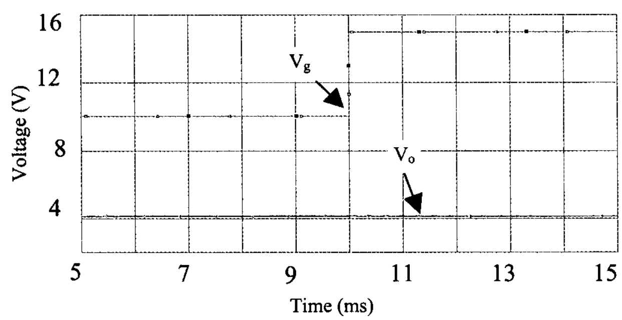

Fig.9. The power source and output voltage using improved one-cycle control

Now the simulation is on about load disturbance. When the load has a disturbance, the load current and the output voltage are shown in Fig. 10 and Fig. 11, the Fig.10 is used one-cycle control technique, the Fig.11 is used improved one-cycle control technique. From the Fig.10 and Fig.11 we can know that the output voltage has more changes with one-cycle control technique than with improved one-cycle control technique when the load current having a disturbance. So the improved one-cycle control technique has more ability than one-cycle control technique about rejection the load disturbance.

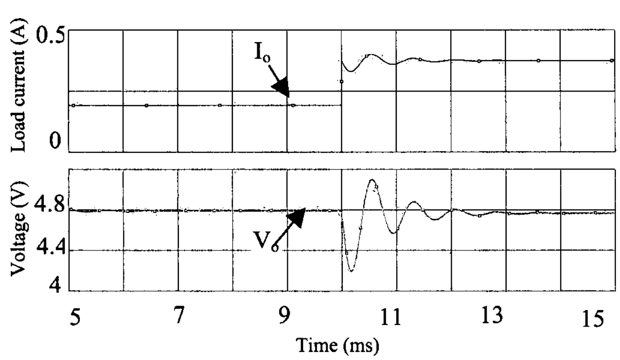

Fig.10 The load current and output voltage using one-cycle control

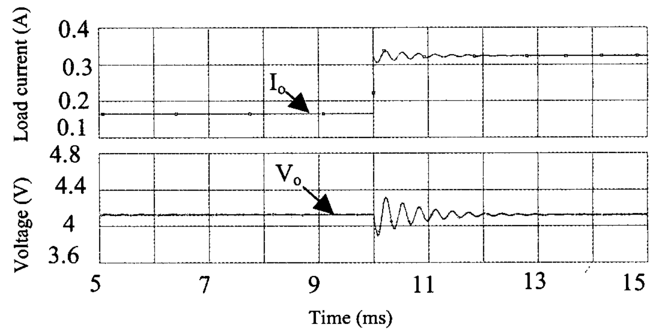

Fig.11 The load current and output voltage using improved one-cycle control

The simulation result have demonstrated that one-cycle control and improver one-cycle control are excellent to reject the power source disturbance, the improved one-cycle control technique has more ability than one-cycle control technique about rejection the load disturbance.

VI. CONCLUSION

An improved one-cycle control technique is proposed in this paper. The simulations have demonstrated that it is excellent to reject power source and load disturbance. The control current is simple, excellent robust performance, fast dynamic response, and so on by using this new technique and this new method can be used in others switching converters.

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