

Implementation of One Cycle Control Technique in Dc-Dc Buck Converter

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Abstract

A nonlinear control technique is used to controls the duty ratio (T) of a switch in switching converters. i.e., an improved one cycle control technique which is conceptual to the concept of technique of one cycle control. This one cycle control method gives firmness to the source side disturbances, but this technique shows infirmness with the load side disturbances. The proposed new improved one cycle control technique rectifies the drawbacks of one cycle control technique. It strongly rejects both source side disturbances and load side disturbances. Simulations with the buck converter results using MATLAB are given to verify the proposed work. To implement and demonstrate the feasibility of this new control technique over the disturbance, an experimental buck converter prototype has been designed, built, and tested.

Keywords: DC-DC Switching Converter, Integrator, Non linear Control, One -Cycle Control Technique, PI Adjustor

1. Introduction

Disturbances on power source side and load side of the system reduces the performances of the system. Thus, a non linear control technique utilizes the nature of the system. Switching converters system has the nature of pulsed non-linear dynamic characteristics. So we can achieve robust performance with fast and excellent dynamic response by using this one cycle control technique with proper pulsed nonlinear characteristics which provides good rejection of source side and load side disturbance than the similar system with linear feedback control technique. To control switching converters for large-signal nonlinear schemes, power electronics community has been a continuous effort in the research.

The Conventional feedback control technique responds to the disturbance occurs in source is slow. The number of switching cycles is required in larger count before it regains its steady-state. Thus, to overcome those problem so many method where taken to consideration.

The paper¹⁻³ proposes the Current-mode control. By using artificial ramp signal we are eliminating the

occurred disturbance which is possible when duty-ratio (T) is 0.5 and above. Based on Theoretical concept, the inductor current falling slope should match accurately with the artificial ramp which we have chosen. Thus, the source perturbations rejection on the system is done by using one cycle control method. The condition may be feasible for the buck converter along with constant control reference. If the precision is made with artificial ramp, the power source disturbance will be rejected in one cycle in the system. In switching converter, normally the inductor current falling slope will be functions of some dynamic states; therefore, the matching of generated artificial ramp with the inductor current falling slope in a transient is not possible. Thus, the rejection of the source side disturbance is not possible within one-switching cycle by using current-mode control. This technique can't able to reject source side perturbations in one cycle and can't follow the control reference under some cases irrespective of the chosen artificial ramp and converter type used in the system.

In feed forward buck-converter, duty-ratio (d) is directly controlled by source voltage before the occurrence

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of error in output voltage. Actually, switches will have its turn-off and turn-on transients and also a voltage drop in its on-state; thus, the accuracy in rejecting the power source perturbation is unable in this scheme.

In this paper⁴ Analog-signal to discrete-time interval converters are introduced. To have the average error to be zero within one cycle of switching period, the closed loop requires an integrator for integrating the error obtained from between the control reference and the switched variable. This is much similar to the continuous time linear integral control. Its steady-state error is zero but the dynamic error is non zero. Apart from this, it won't be stable when duty ratio (d) is 0.5 and above.

A nonlinear control method that Sliding-mode control is proposed in this paper⁵. This paper defines sliding surface moving through a convergence point i.e., a desirable operating point. Normally, it needs many switching cycles for motion of system to converge with the desirable operating point and the switching frequency variable.

This paper^{6,7,11} proposes an alternative non-linear control method as one cycle control method. The non-linear and the pulsed characteristics of switching converters are taken as advantage and achieve instantaneous dynamic control on switched variable's average value. Mainly, the switched variable's average value will reach a reformed steady-state with one cycle of switching period after the transient period. Thus it needs only one cycle to control the disturbance and along with this, its steady-state error is zero and the dynamic error is also zero in between the control reference and the switched variable's average value. This control technique achieves robust performance, excellent source side disturbance rejection, error correction in automatic switching and fast dynamic response. Even-though one cycle control method having too many series merits, this shows its infirmness with the occurrence of load side disturbance.

State feedback is proposed in the paper⁸. This method proves the excellent rejection with the load side disturbance, but for the source disturbance it shows infirmness in the system. The proposed paper with Function control method^{9,10}, whereas both source side disturbance and load side disturbance rejections are better, but while looking towards the response, it is slow. Main demerits are, it can be easily disturbed, control current is complex and ratio of performance to price is low.

This proposed paper is non-linear control technique, improved one cycle control-technique which is totally same as one cycle control technique. This method

overcomes the shortcoming of infirmness on source side disturbance and load side disturbance rejections. The PI adjuster is added along with one cycle control-technique to obtain the improved one cycle control-technique. It gives robust performance, fast excellent dynamic response, and zero steady state and dynamic errors. Simulations with buck converter results using MATLAB are given to verify the proposed work. To demonstrate the feasibilities of this control-technique over a wide variation of disturbance, an experimental buck converter prototype has been designed, built, and tested. The proposed work's block diagram is shown in Figure 1

2. One-Cycle Control

The buck converter is taken as example in this new control concept. Figure 2 shows the buck converter. The buck converter shows the feasibility of this new control technique over a wide variation of disturbance.

2.1 One Cycle Control Concept

In this buck converter, the source voltage (V_g) as DC supply is given and switch-S will operate with constant-frequency ($f_s = 1/T$). When we on the switch, the diode will be in off-state and the diode voltage (V_s) is equal to the source voltage (V_g). When the same switch is off, the

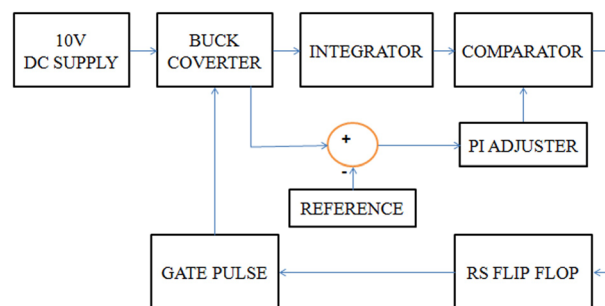


Figure 1. Block diagram of the proposed work

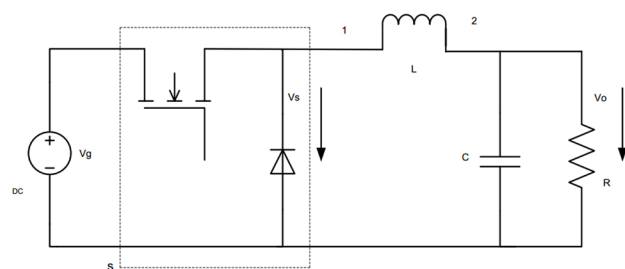


Figure 2. The buck converter

diode will be in on-state, and the voltage across the diode will be zero. The switching variable is resulted by chopping the source voltage by the switch. Mostly, the undesirable switching frequency components were rejected and the switched variable average is transmitted to output by low-pass filter. Thus, the output voltage will have dug of some desired D-C value and a small ripple in the residual switching. Figure 3 shows the one cycle control concept with buck converter.

The switched variable's average value is buck converter's output voltage. In this case, the voltage passing through the diode is equivalent to the area of each pulses of the switching period divides voltage passing through the diode.

$$V_s = \frac{1}{T_s} \int_0^{T_s} v_s dt = \frac{1}{T_s} \int_0^{dT_s} v_g dt$$

By a constant frequency clock, switch is turned on at the starting of each switching cycle period. The voltage passing through the integrated diode and the control reference is compared. Once the voltage passing through the integrated diode attains the given control reference, the state of comparator changes accordingly. Thus, it turned off the belonging switch and resets zero to the integrator.

Under constant control reference, the average value of the voltage across diode will be constant and the respective output voltage as we shown in Figure 4. The supply source voltage is directly proportional to the integration slope. The value of integration and the constant control reference are compared continuously. If the higher voltage is passing through source, the integration slope will be steeper. Thus, the duty-ratio *d* is smaller and the value of integration reaches the reference of control signal

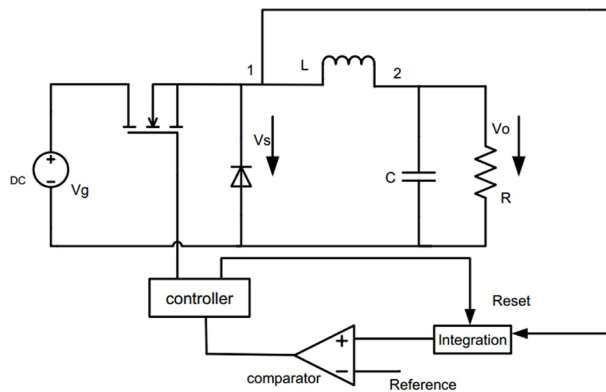


Figure 3. The one cycle control concept with buck converter

faster. When the lower voltage passing through source, the duty-ratio (*d*) will be in larger.

Under variable control reference, the voltage average value across diode will be equal with the time variant control reference of system in every cycle since the control reference is a function of time which is shown in the Figure 5.

The duty-ratio *d* of this control scheme is determined by

$$\frac{1}{T_s} \int_0^{dT_s} v_g dt = v_{ref}$$

Finally, this new nonlinear control scheme provoked the current switching cycle duty-ratio (*d*) and the previous switching cycles state duty ratio (*d*) are independent. The transient effect on switched variable is done within one cycle of switching period.

The duty-ratio obtained above is a non-linear function of the voltage across the source and the system control reference. Due to the above non-linear control scheme,

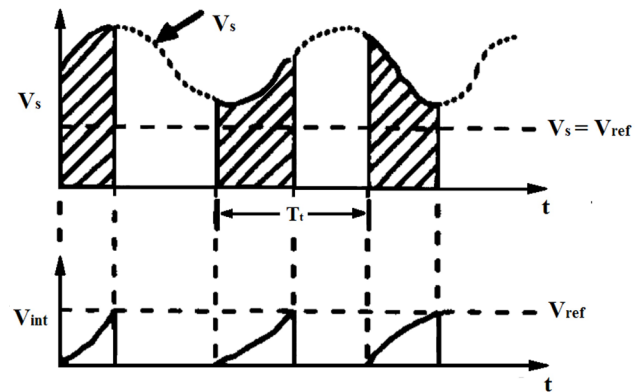


Figure 4. Constant control reference

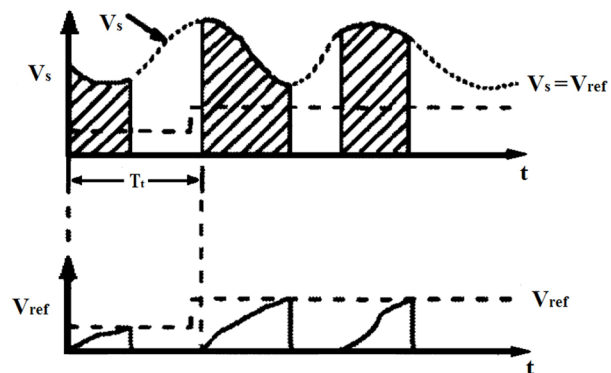


Figure 5. Variable control reference

the buck converter show linear functionality between system control reference and the voltage across output is independent of the source voltage,

$$v_0 = \frac{v_{ref}}{1 + \frac{L}{R}S + LCS^2}$$

2.2 One-Cycle Control Theory

According to the switch function $k(t)$ the switch will operate at the frequency $f_s = 1/T$,

$$k(t) = \begin{cases} 1, & 0 < t < T_{ON} \\ 0, & T_{ON} < t < T \end{cases}$$

In each and every cycle, the switch will be in on state for a (T_{on}) and the switch will be in off state for a small duration of time of (T_{off}), where the summation of the time T_{on} and T_{off} is total time duration T of a cycle. The duty-ratio d of the system is the ratio of ON time duration (T_{ON}) of switch to the total time duration (T_{ON}/T) of switch which will be regulated by using an analog control reference $W_{ref}(t)$. In the switch, at the input node, the respective input signal $Z(t)$ is chopped by the switch and the switch transfers those chopped signal to the output node of the switch to form the switched variable $y(t)$. Thus, switch function $k(t)$ is same as the pulse width and the frequency of the switched variable $y(t)$, whereas the switched variable $y(t)$ envelope also same as the in/put signal $x(t)$,

$$y(t) = k(t)x(t)$$

If the switch frequency (f_s) becomes higher than the frequency bandwidth (BW) of either control reference $W_{ref}(t)$ or input signal $x(t)$, then the switched variable average at switch output i.e., effective signal, is

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

At the switch's output node, the switched variable $y(t)$ of the system will be the product of the duty-ratio $d(t)$ and the input signal $z(t)$; thus, the switch in the system will be non linear.

The integration of the switched variable of the system is made totally equal to the integration of the system's control reference by regulating the duty-ratio in each cycle of the switch, i.e.,

$$\int_0^{T_{ON}} x(t)dt = \int_0^{T_s} V_{ref}(t)dt$$

If the switching period is constant in each cycle, then the switched variable average value is precisely equal to the system's control reference. Thus, the switched variable average is at switch output is controlled instantaneously within one cycle of time duration, i.e.,

$$y(t) = \frac{1}{T_s} \int_0^{T_{ON}} x(t)dt = \frac{1}{T_s} \int_0^{T_s} V_{ref}dt = V_{ref}(t)$$

The nonlinear technique used for controlling the switches based on the concept of the "One cycle Control Technique". With this One cycle Control technique, the effective output signal of the switch will be

$$y(t) = V_{ref}(t)$$

In this One cycle Control Technique, the nonlinear switch leads the system into the linear path by doing rejection on input signal of the switch and linearly passing the control reference W_{ref} .

Figure 6 shows the constant-frequency switch by the implementation on one cycle Control circuit. The re-setter and the integrator are the main components of this proposed one cycle Control technique. As we turned on the switch with the fixed frequency clock pulse, the integration gets starts. The integration value is,

$$V_{int} = k \int_0^1 x(t)dt$$

Where k is a constant. The integration value and the control reference $V_{ref}(t)$ are compared immediately without any delay. Thus, controller made that switch to turned off when the value of integration V_{int} reaches the control

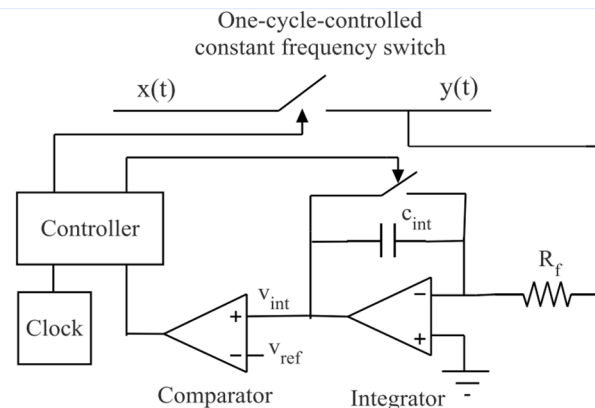


Figure 6. The constant-frequency switch

reference $V_{ref}(t)$ and automatically controller resets zero to the value of integrator. The following equation gives the present cycle duty ratio (d) to calculate:

$$k \int_0^{dT_s} x(t)dt = V_{ref}(t)$$

Thus, the switch period (T) and $K = 1/kTs$ both are constant. Thus, the switched variable's average value in each cycle at the output of the switch $y(t)$ is admitted as

$$y(t) = \frac{1}{T_s} \int_0^{dT_s} x(t)dt = \frac{1}{kT_s} V_{ref}(t)$$

The operating waveforms of above circuit are shown in the Figure 7, when V_{ref} is constant.

3. Improved One cycle Control Technique

Although one cycle control technique does the rejection in excellent form on source side perturbations, that system shows its infirmness towards the load side perturbations. The novel proposes a nonlinear control technique, improved one cycle control technique that overcomes the defects of that one cycle control technique. The buck converter with implementation of the improved one cycle

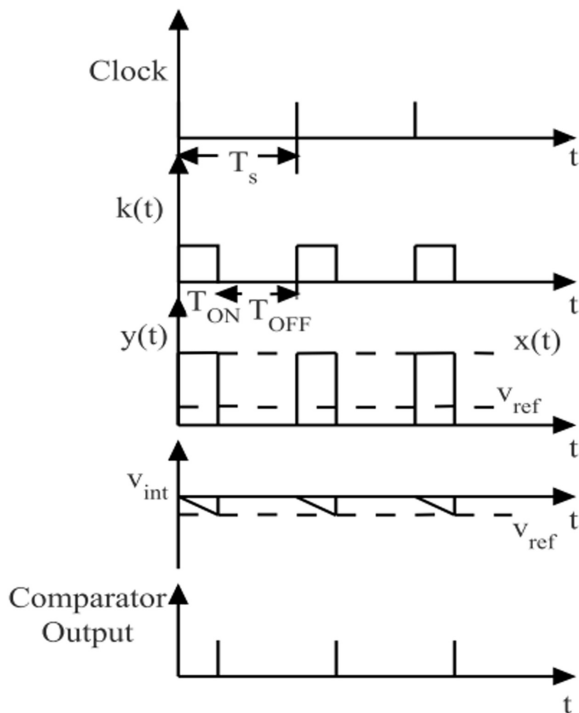


Figure 7. The waveform of the one cycle control circuit

control technique is shown in the Figure 8. The one cycle control technique takes the diode voltage to integrate and to compare with the control reference, such that the duty ratio can be adjusted to rejection on the source side perturbations whereas in the improved one cycle control technique, the output voltage related to the control reference to get the error signal which is operated by the PI adjuster and it is given to the comparator of the newly proposed control technique. The output of PI adjuster will be constant at stable state.

The one cycle controlled current is equivalent to improved one cycle controlled current when source side attains a disturbance in the system. The process of adjusting the improved one cycle control technique is same as adjusting in the one cycle control technique. To reject the power source disturbance, only one cycle is enough to complete the adjustment in the one-cycle control technique. So it has excellence performance to reject the power source perturbations.

When the disturbance on load side comes into picture, the output voltage with reference generates error signal which change at once. The PI adjuster operates with that generated error signal and the output belonged to the PI adjuster is given to comparator as reference. Due to change in comparator reference, the duty ratio related to that will change at once. The same process is preceded for one cycle control technique when the respective control reference is variable. The output belonging PI adjuster retains its remarked value of that PI adjustor at stable state when the voltage across output achieved its stable steady state. Thus, the improved technique could do the rejection on load side perturbations.

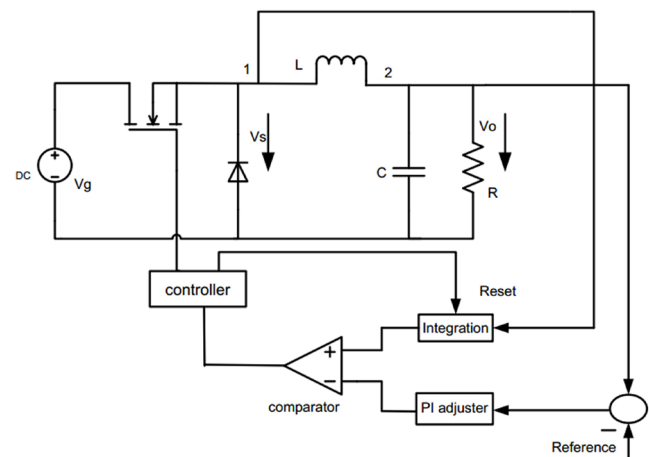


Figure 8. The improved one cycle control technique

4. The Simulation and Experimental Results of Improved One- cycle Control Technique

The improved one cycle control technique with buck converter is done with the computer simulation and is demonstrated which is shown in the Figure 9. The designed control technique is simulated with buck converter using MATLAB to verify the proposed technique. To obtain the simulation results, simulation has run with the operating condition of switch time $T = 20 \mu$, capacitance (C) = 30 pf and resistance (R) = 30 ohm and inductance (L) = 0.48 mH

Initially, the voltage across input and the current of the converter with disturbance on source side and load side from voltage level of 10V to 15V are displayed in Figure 10 and Figure 11. The Figure 10 obtained with the one cycle control technique and the Figure 11 is obtained with the improved one cycle control technique. By observing both the Figure 10 and Figure 11, we could come to the conclusion that the voltage across input of improved one cycle control technique shows better result than one cycle control technique when having the disturbance on source side.

Finally, the current through load and the voltage across output of the converter with disturbance on source side and load side from voltage level of 10V to 15V are shown in Figure 12 and Figure 13. The Figure 12 obtained with the one cycle control technique and the Figure 13 is obtained with the improved one cycle control technique. By observing the Figure 12 and 13, we can conclude that

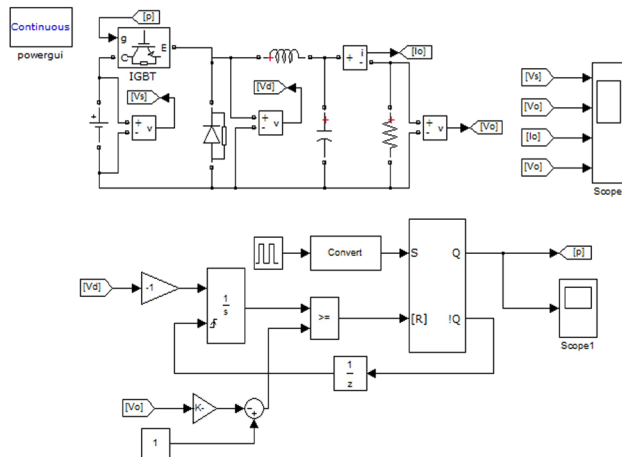


Figure 9. The buck converter with improved one cycle control technique

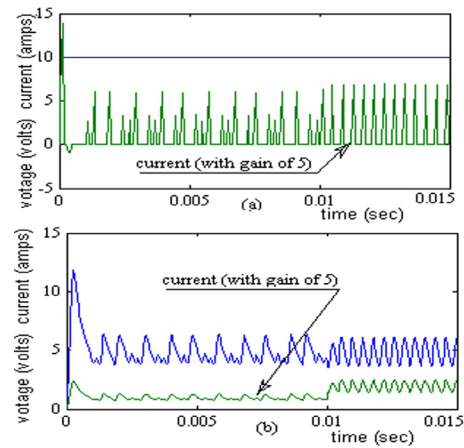


Figure 10. Voltage and current with one cycle control with load power disturbances at (a) Input side (b) load side

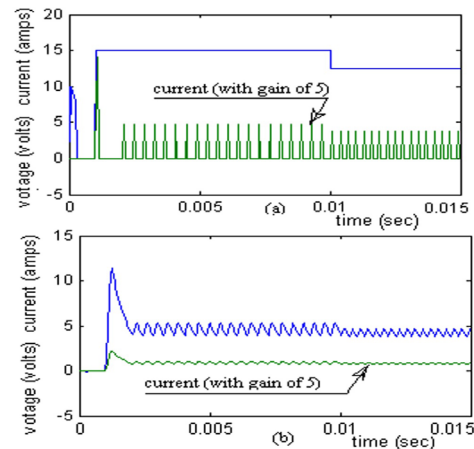


Figure 11. Voltage and current with one cycle control with source power disturbances at (a) Input side (b) load side

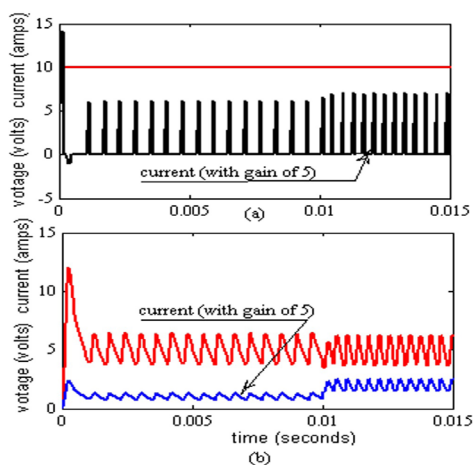


Figure 12. Voltage and current with improved one cycle control with load power disturbances at (a) Input side (b) load side

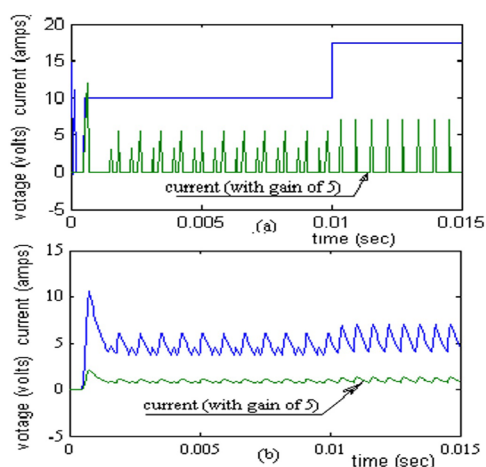


Figure 13. Voltage and current with improved one cycle control with source power disturbances at (a) Input side (b) load side

the output voltage and the load current show better result with improved one cycle control-technique. Thus, the improved one cycle control-technique has more feasibility on rejecting the load disturbance.

The simulation result of converter have demonstrated with the one cycle control technique and the improved one cycle control technique, where does effective work for excellent rejection on the source side disturbance and the load side disturbance. Thus, the improved one cycle control technique having more feasibility than one cycle control technique.

5. Conclusion

The proposed paper of large signals improved one cycle control-technique shows the source side disturbance rejection and load side disturbance rejection in excellence. An improved one cycle control-technique is designed to control the duty-ratio (d) of the switch dynamically, therefore the control reference in each cycle is precisely equivalent to the switched variable's average value. The effective output signal is capable to trace the control reference within switching period of one cycle. The error correction of switching is done automatically within the switching period of one cycle. Thus, there is no possibility of getting the steady state error and dynamic error. i.e., both are zero.

The important objective of this proposed paper is to control the disturbance on both source side and load side within one cycle and to demonstrate the feasibility of this new improved one cycle control-technique and to verify the simulation results of improved one cycle control technique.

The simulations of this buck converter with this improved one cycle control-technique have demonstrated that it has fast dynamic response, excellent robust performance, control current is simple and so on and this improved technique can be implemented in others type of switching converters.

6. References

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