Research On Double Transistor Nonlinear Controlling Strategy

Jianjun Xu, Jianyu Liu, Lianwei Zhang

College of Electrical Information Engineering, Northeast Petroleum University, Daqing, P. R. China

Abstract

The PWM switch converter essentially belongs to the nonlinear control system. Based on the PID control converter in the system dynamic response, robustness is very difficult to obtain satisfaction the control effect. The comprehensive survey domestic and foreign proposed in recent years several kind of non-linear controls strategy, the one-cycle control has the big superiority in the control effect and the project realization aspect, and has been applied in some PWM converter. The one-cycle control through uses a non-linear integrator, forces the switch converter medium in each switch cycle in the datum, crossed the converter output stage, thus reduces the systems control step number, causes the system to suppress inputs the dynamic response which the power source disturbs to enhance greatly. The one-cycle control shortcoming mainly is to the switch error adjustment ability limited, the system existence static error, at the same time the system load dynamic speed of response is slow. In view of the one-cycle control existence question, Research team proposed one kind of improvement one-cycle control new strategy, namely the exact cycle integral function control, and studied the exact cycle integral function control which the belt forward feed compensated in double transistor to stir up in the converter the application, has confirmed this control strategy validity and the feasibility through the simulation.

Keywords

Nonlinear Control, The Exact Cycle Integral Function Control, Double transistor Forward, Simulation.

1. Introduction

Owing to the superiority of low voltage stress of the switch tube, the input and output isolation, and can realize multiple output voltage and so on, Double Forward Converter is a topology used frequently in switch power converters[1]. Control method often adopts voltage single loop or voltage-current double closed loop linear feedback control theory. Due to the switching power supply is a very strong nonlinear system. Application of linear feedback control systems in switching power supply controlling can not satisfy the control effect of system dynamic response, robustness and steady-state error. Therefore, in recent years, many domestic and foreign scholars have made a deep research on the control strategy of switching power supply, and have proposed kinds of non-linear controls strategy such as sliding mode variable control[2], fuzzy control[3], One-Cycle Control[4] and so on, which have made some progress.

One-Cycle Control uses a non-linear integrator, forces switch variable in each cycle is exactly equal to the control reference, improving the system dynamic response of inhibiting the input power disturbances and tracking control criterion change dramatically. However, One-Cycle Control has the disadvantages of slow load disturbance dynamic response and steady state error of the system.

Based on the above disadvantages of single-cycle control, research team proposed one kind of improvement one-cycle control new strategy, namely the exact cycle integral function control, and studied the exact cycle integral function control which the belt forward feed compensated in double transistor to stir up in the converter the application, has confirmed this control strategy validity and the feasibility through the simulation.

2. Fundamental principle of exact cycle integral function control

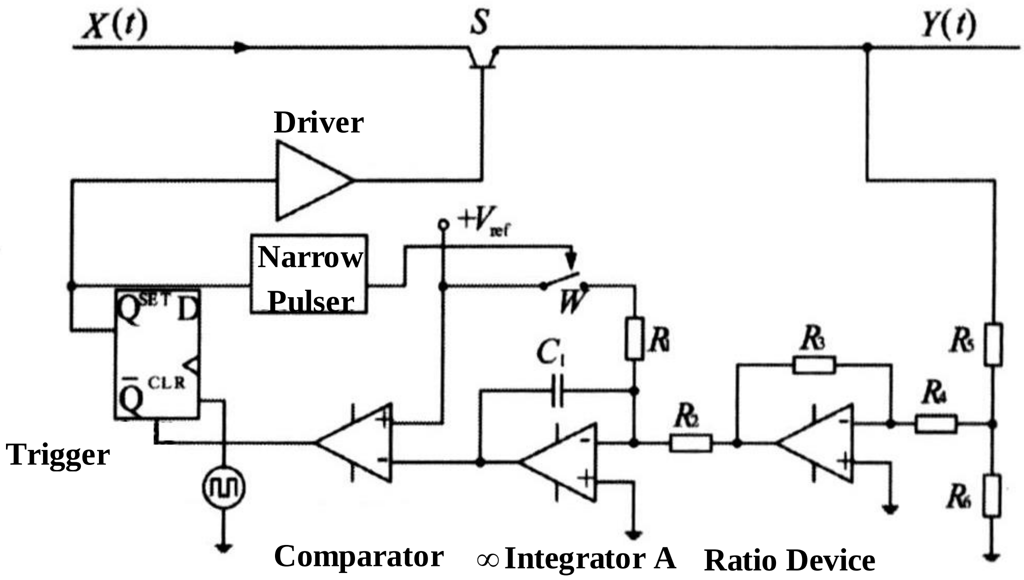

Figure 1 Switch regulator of exact cycle integral function control

The working principle of exact cycle integral function control switch regulator is shown in figure 1. The system consists of an operational amplifier, nonlinear integrator, comparator, divider, narrow pulse generator and reset switch. The working waveform of each point of the controller is shown in figure 2. At the time of the arrival of the pulse rising edge of the clock, The flip-flop is set（Q=1）, the drive switch S is turned on, the switch output $y(t)=x(t)$. After sampling circuit and operational amplifier, the signal $y(t)$ is changed into V_p, And connected to the integrator to output integration of signal $y(t)$. The output of the integrator, V_{int}, began to grow linearly in the forward direction from initial value of V_{r1}.When V_{int} reaches control reference value V_{ref}, the comparator output flips, the D flip flop reset（Q=0）, Switch S off. Off signal generates a signal By means of a narrow pulse generator at the same time, turning off the reset switch W and achieving reverse linear reset of integrator. It is worth noting that the integrator output in this process is not reset to zero (integrator of one cycle control in each period will be completely reset), but according to the size of the output $y(t)$ and the unique switching time of the controlled switch S itself, automatically reset to an initial value (for example V_{r1}). When the next clock cycle arrives, integrator restarts next cycle of the integral work from the reset value of previous cycle, and again and again.

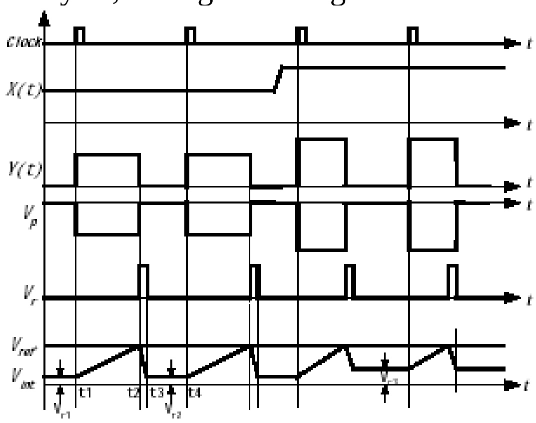

Figure 2 Work waveform of exact cycle integral function control

Assume that the initial value of integrator at the time of t_1 is V_{r1}, then the integrator output V_{int} at the time of t_2 can be expressed as:

$$V_{\text{int}} = V_{r1} + \frac{k_1 \cdot k_2}{R_2 C_1} \int_{t_1}^{t_2} y(t) \cdot \mathrm{d}t = V_{ref}(t) \tag{1}$$

When the integrator output reaches comparator threshold, flip flop reverses, the integrator is reset. The initial value V_{r2} of integrator at the time of t_4 can be calculated with the following formula:

$$V_{r2} = V_{ref} + \int_{t_2}^{t_3} \left[\frac{-1}{R_1 C_1} \cdot V_{ref}(t) + \frac{k_1 \cdot k_2}{R_2 C_1} \cdot y(t) \right] \cdot \mathrm{d}t + \int_{t_3}^{t_4} \frac{y(t)}{R_2 C_1} \cdot \mathrm{d}t \tag{2}$$

In the formula: k_1, k_2—Sampling resistor divider ratio and proportional amplifier gain.

When the system is in steady state operation, the integrator initial value of converter adjacent switch cycle necessarily equal, that is $V_{r1} = V_{r2}$. So it can be deduced:

$$\int_{t_1}^{t_4} \frac{k_1 \cdot k_2}{R_2 C_1} \cdot y(t) \cdot dt = \int_{t_2}^{t_3} \frac{1}{R_1 C_1} V_{ref}(t) \cdot dt \tag{3}$$

Because the reset pulse generated by a narrow pulse generator is constant, assume that: $T_{reset} = t_3 - t_2$, switching cycle $T_s = t_4 - t_1$, then obtain the following equation:

$$\int_0^{T_s} \frac{k_1 \cdot k_2}{R_2 C_1} \cdot y(t) \cdot dt = \int_0^{T_{reset}} \frac{1}{R_1 C_1} V_{ref}(t) \cdot dt \tag{4}$$

The integral time for the upper left of the equation is T_s, that is in the time period after the capacitor is reset(Before the next clock comes), all output information of the controlled switch(Including the output due to the switching time of the power tube) will enter the integrator totally, which ensures that no output information is lost during the reset period, achieving a complete correction of the converter switching error.

3. Features and improvements of exact cycle integral function control

In exact cycle integral function controller, the integrator of core part does not adopt the parallel switch reset mode (Single cycle control using parallel mode) but introduces a narrow pulse linear backward reset. The advantage of this reset method is that: The output signal of controlled variables works as input of integrator in the whole closed-loop control process, therefore, in each switching cycle, the output of the integrator can not be completely reset to zero but automatically reset to an initial value according to the actual physical characteristics of the controlled switch variable. The signal amplitude of the controlled switch variable is higher, the initial value of integrator after reset is greater, so the time of the integrator output reach to control reference V_{ref} in the next cycle is correspondingly shorter. The difference between integrator initial values of adjacent switch cycle is proportional to the switching error:

$$\Delta V_i = V_{i1} - V_{i2} = k \cdot \int_0^{T_{reset}} \left[y_1(t) - y_2(t) \right] \cdot \mathrm{d}t \tag{5}$$

If the input signal does not change in the adjacent switching cycles, the input signal is zero. The scheme achieves a complete correction of the switching error of the converter. So it is an important improvement over single-cycle control.

It should be noted that there is also another problem after exact cycle integral function control solving the problem of switching error in single cycle control, that is the integrator will cause saturation and system oscillation while the hopping of converters load lead inductor current to change from continuous mode (CCM) to discontinuous mode(DCM). This problem also exists in the single cycle control. After careful analysis, it is inductor current is zero that lead integrator saturation. Diode voltage equals to the output voltage V_0, and this time V_0 has a serious overshoot due to load disturbance, the peak value is greater than the steady state value of output voltage. Therefore, before integrator starting from the initial value to the next clock to the arrival of the clock, it will achieve control benchmark and flip the comparator. And because the previous flip flop is in the off state, the comparator flips without changing the state of the trigger. Thus it is impossible to generate a reset signal. So the integrator will continue to integral and eventually lead to saturation.

For this purpose, research team proposed countermeasures which adopts exact cycle integral function controller with he function of automatic limiting integrator. The measure can solve the problem of system oscillation caused by the load jump of the converter.

At present, the output element of the PWM switch converter adopts low pass filtering link consist of inductance capacitance, the time constant of LC filter is usually very large, so the filter is actually turned into a large inertia link. But the ability to restrain the load disturbance is not ideal, and other improvement measures must be studied. In the automatic control system, in order to eliminate the influence of the disturbance to the output, add feed-forward control which is more timely than feed-back control and will not be affected by the delay of the system. Feed-forward control is widely used in the system requires the output to be able to follow the input quickly. In terms of switching converters, load current or filter capacitance current is an external disturbance signal. When the load of converter suddenly increase or decrease, the DC output voltage will be affected firstly deviating from the set value. Then system enters steady state again by adjusting voltage close loop regulator. But due to the effect of output low pass filtering time constant, the regulating function of the voltage regulator is slow. So introduce reasonable designed load current feed forward control in the PWM switch converter will significantly improve the load dynamic response of converter.

4. Double transistor forward converters of exact cycle integral function control with feed-forward compensation

Double transistor forward converters of exact cycle integral function control with feed-forward compensation is shown in Figure 3: Main topological structure uses double transistor forward converters. This is because the voltage stress of each switch tube is half of the output voltage, which reduces the cost of the converter. The control circuit is composed of integrator, comparator, D flip-flop, driver, narrow pulse generator. Double feed forward feedback control uses capacitive current and output voltage. Assume that the switching tube S_1, S_2, D_1, D_2, D_3, D_4 are all ideal components.

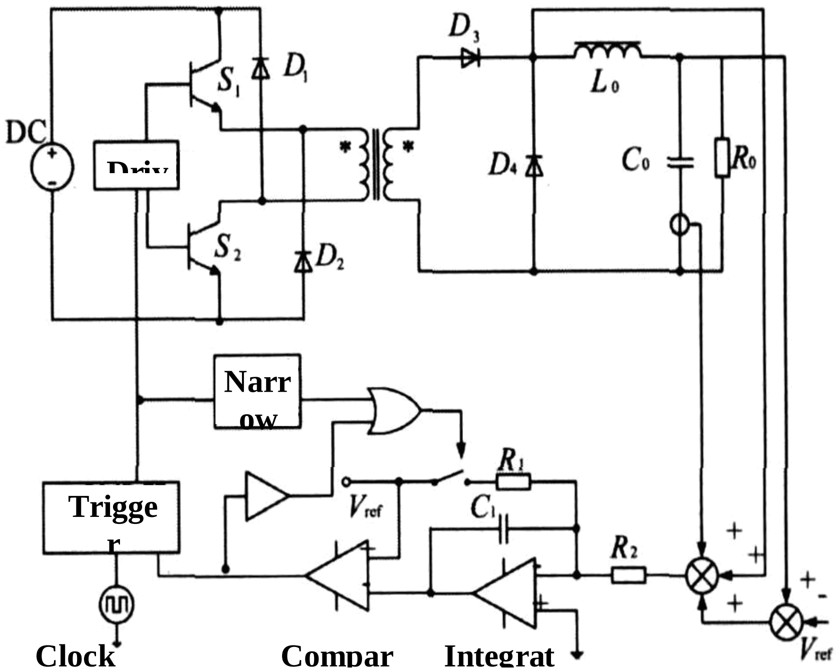

Figure 3 Double transistor forward converters of exact cycle integral function control with feed-forward compensation

Double transistor forward converters of exact cycle integral function control works as follows: At the time of the rising edge of the clock, because of the high level of the D trigger, the D trigger is set, and the output is high, the switch S1, S2 is turned on by the drive. The input voltage is reduced by the high frequency transformer, getting switching pulse V_D at the secondary side diode. The changing switching pulses enter the integrator in real time. When the integrator output V_{int} is equal to the control reference V_{ref}, comparator flips, so D flip flop reset. When the driver drives the switch tube S1, S2 to turn off, the switch of secondary side turns on to lead the energy stored in the inductor to continue to flow through the diode D4, maintaining stability of output voltage. At the same time the D trigger is reset, narrow pulse generator produces a narrow reset pulse, driving the reset switch W to reset integrator. This work cycles again and again.

Exact cycle integral function has a strong inhibitory effect on the disturbance of the power supply, simultaneously, has a good correlation effect on the disturbance of the control reference. When the load is disturbed, the dynamic response is slow, the overshoot is serious, and the transition time is long. In order to suppress the load disturbance, a disturbance signal is obtained by detecting the filter capacitor to obtain the disturbance information of the load, and the other one is from the output voltage.

After the double feed-forward compensation network, the formula (4) is changed into:

$$\int_0^{T_s} \frac{k_1 \cdot k_2}{R_2 C_1} V_D \cdot dt + \int_0^{T_s} i_c(t) \cdot dt + \int_0^{T_s} V_0(t) \cdot dt = \int_0^{T_{ret}} \frac{1}{R_1 C_1} \cdot V_{ref}(t) \cdot dt \tag{6}$$

In the above formula, when system in steady state, detection current of the filter capacitor is a periodic change of the symmetric time axis, so its integral in a switching cycle is zero. The output voltage in a switching cycle is zero. That is:

$$\int_0^{T_s} i_c(t) \cdot dt = 0 \tag{7}$$

$$\int_0^{T_s} V_0(t) \cdot dt = 0 \tag{8}$$

So, after the introduction of double transistor forward converters of double feed-forward exact cycle integral function control, its steady state output is the same as that without double transistor forward converters of double feed-forward exact cycle integral function control. That is:

$$\int_0^{T_s} \frac{k_1 \cdot k_2}{R_2 C_1} \cdot V_D \cdot dt = \int_0^{T_{ret}} \frac{1}{R_1 C_1} \cdot V_{ref}(t) \cdot dt \tag{9}$$

By the above analysis, we can know that the disturbance of the load can be eliminated and achieve static no difference of the input power supply change.

5. Conclusion

Research team proposed new strategy of exact cycle integral function, summarized its characteristics and proposed modified double feed-forward exact cycle integral function control strategy. Adopt exact cycle integral function control with feed-forward compensation in double transistor forward converters. Analysis and verify the disturbance of suppress power supply, suppress control reference and suppress load of this control strategy through the simulation waveform. It can concluded from theoretical analysis and simulation results that the exact cycle integral function control with feed-forward compensation basically achieves the optimal control, the dynamic response is fast and can achieve no errors at stable state.

Reference

[1] Zhang Zhansong, Ca Xuansan. The Principle and Designment of Switching Power Supply. BeiJing: Publishing House of Electronics Industry,2011.

[2] R.Venkataramanan,A.Sabanovic,and S. Cuk, Sliding Mode Control of DC-to-DC Converters.

IEEE IECON,2015: 251~258
[3] So, W.C, Tse, C.K.Lee, Y.S. A Fuzzy Controller for DC-DC Converters. IEEE PESC 1994: 315~320
[4] Smedley Keyue M, Cuk Slobodan, Dynamics of One-Cycle Controlled Cuk Converters. IEEE Transactions on Power Electronics. 1995: 634~639
[5] XU Feng, XU Dian-guo, LIU Yu-xiu. A Novel Nonlinear Control Method for PWM DC-DC Converter with Optimizing Transient Response. Proceedings of the CSEE, 2013, 23（12）: 133~139
[6] LIN Wei-ming. A New Open-Loop Control Strategy for a DC-DC Switching Converter with Fast Load Transient Response. Proceedings of the CSEE,2011,21(9)78~81
[7] Calderone, Pinola, Varoli. Optimal feed-forward compensation for PWM DC/DC converters. IEEE Power Electronics Specialists Conference, 2011：235~241