Hybrid control of high power factor AC/DC regulated power supply

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Abstract. The control circuit of two-stage power factor correction(PFC) is complex, and the volume of power supply is large because of high voltage ripple of the first stage filter capacitor. Towards to this deficiency, a two-stage PFC circuit based on chip and ARM hybrid control is designed. The first stage is Boost converter with UC3854 PFC regulator, and the second stage is double forward DC/DC converter controlled by ARM with one cycle control algorithm. A switches synchronous method to decrease the output voltage ripple of the first stage circuit is proposed, which is taking the driving signal's falling edge of the first stage as the trigger signal to control the MOSFET of the second stage circuit conduction when the switch of the first stage is off. Simulation of the overall system is conducted in Matlab/Simulink, the result show the design of control strategy and circuit parameters are reasonable, the power factor, the total harmonic distortion(THD), the output voltage ripple of the first stage are effectively improved, and the whole system has good inhibitory effect on input voltage and load disturbance.

Keywords: two stage PFC circuit; hybrid control; double forward DC/DC converter; switches synchronous method.

1 Introduction

The advantage of two-stage PFC circuit is high power factor and fit for high power application, but the control circuit is complex. Generally, the MOSFET of two-stage circuit are on simultaneously[1]. Thus, the output voltage ripple of the first stage will be increase. In order to limit the voltage ripple to a required range, the large capacitor will be used. Accordingly, the volume of whole power supply will be increased.

For this problem, Two stage PFC circuit is designed by adopting PFC and PWM controller combo ML4803 and ML4824 in current study[2,3], the control essence of which is employing Leading Edge Modulation(LEM) for the first PFC stage and Trailing Edge Modulation(TEM) for the second DC/DC stage to reduce the cost and volume of two stage PFC circuit. In this paper, a digital control strategy based ARM platform is proposed to make the switch of first stage close and the switches of second stage open synchronously at each cycle beginning. Thus, the most energy stored in the boost inductor can be directly provided to the second stage without going through the filter capacitor, and the voltage ripple can be decreased. Compared with analog control, this control strategy can simplify circuit structure, reduce cost and realize flexible control of the power supply.

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2 The system structure

As shown in Fig1, The system consists of rectifier and filter circuit, Boost converter circuit, UC3854DW control circuit, sampling circuit, double forward DC/DC converter circuit, ARM control circuit, ARM power circuit, isolation sampling circuit, and driving circuit.

Figure 1. The structure of two stage PFC circuit

The input alternating voltage becomes a half sinusoidal direct current through the rectifier and filter circuit, Boost PFC circuit controlled by high power factor pre-regulator UC3854DW is used to correct the power factor, and double forward DC/DC converter circuit is used to convert the voltage to the required voltage. ARM controller is mainly used to realize the one cycle control[4,5,6] and PID control program to compute the duty cycle.

3 The system hardware design and control strategy

The system design index: input voltage is 85V~265V/50Hz, the frequency of switches are all 100kHz, the output voltage of the first stage is 400V, the power factor is above 0.95, the output voltage of second stage is 45V, and the output power is 900 W.

3.1 The control circuit and parameters design of the PFC circuit

As shown in Fig.2, in Boost PFC circuit, the control core is internal multiplier of UC3854DW, through sampling input voltage V_{in} , input current I_{in} and output voltage V_{o1} , the PWM signal is generated to force the input average current to be in phase with the input voltage, so the power factor is close to 1.

Figure 2. Boost PFC circuit controlled by UC3854

In this design, the role of input capacitor is to filter out the high frequency voltage ripple, generally choosing 1uF. According to theory calculation of Boost PFC circuit[7], the minimum value of the boost inductor is 258μH, taking 1mH in practice, the value of output filter capacitor is 250μF, taking 470μF in practice.

3.2 The control strategy and parameters design of DC/DC converter

The control schematic of double forward converter is shown in Fig.3. For realizing switches synchronization control, the PWM signal's falling edge of the first stage sampled by ARM is acted as trigger signal of one cycle control to make the switches of DC/DC circuit open when the switch of the first stage close. Through controlling the open time of DC/DC switches, the integral value of switch

variable in a cycle will be strictly equal or proportional to the given reference value V_m , which is the output of PID controller.

Figure 3. The control schematic of double forward converter

The switches of double forward converter open and close simultaneously. Assuming that the voltage of transformer's secondary winding is u_s , the output voltage is u_o , the voltage of the diode VD4 is u_d . Then, $u_d = u_s$ when VT2 and VT3 is open, otherwise, the value of u_d is 0. According to one cycle control theory and the equation of circuit output side, we have Eq(1)

$$LC \frac{d^2 \bar{v}_o}{dt^2} + \frac{L}{R} \frac{d \bar{v}_o}{dt} + \bar{u}_o = k \bar{u}_s = \bar{u}_d \quad (1)$$

From the transfer function of PID controller after averaging, combining Eq.(1), we have Eq.(2)

$$LC \frac{d^3 \bar{v}_o}{dt^3} + \left(\frac{L}{R} + k_d \right) \frac{d^2 \bar{v}_o}{dt^2} + (k_p + 1) \frac{d \bar{v}_o}{dt} + k_i \bar{v}_o = k_i v_{oref} \quad (2)$$

Through discretizing Eq.(2), we can not only obtain the incremental PID equation but also see that the output voltage can follow the reference voltage V_{ref} well through selecting the parameters k_p , k_i , k_d of the PID regulator. The integral variable of one cycle is U_d , and the reference U_m of one cycle is the output of PID regulator. Final, the duty cycle can be described as $d = u_m / u_d$.

In this design, the soft magnetic ferrite core ETD-44 is chosen to design the transformer, and the turns ratio N is 3.29, the original side is 46 turns, vice side is 14 turns. According to the computational formula of induction and capacitor in double forward converter, we can obtain $L1 = 70.9 \mu H$, $C3 = 22.2 \mu F$, taking $L1 = 100 \mu H$ and $C3 = 470 \mu F$ in practice.

4 The simulation waveform and result analysis

In order to verify the correctness of the control strategy of the system, the simulation model is built in Matlab/Simulink.

4.1 Simulation result

The simulation result of power factor, the input total current harmonic distortion, and the voltage ripple of filter capacitor in different simulation condition is shown in table.1. From table.1, we can obtain THD_I is about 7%, and the power factor can reach 0.9975. After adopting the switch synchronization control, the voltage ripple of filter capacitor is reduced about 21%.

Table1. The simulation result at different input voltage and load disturbance

Input voltage	Load	THD _i	PF	Ripple voltage before	Ripple voltage after	Output voltage
85V	2.25Ω	6.91%	0.9975	23.5V	18.5V	44.99V
	22.5Ω	11.6%	0.9910	11V	8.6V	45V
220V	2.25Ω	7.85%	0.9916	20V	15.8V	44.93V
	22.5Ω	5.83%	0.9864	5V	4.1V	44.94V
265V	2.25Ω	7.88%	0.9887	21V	16.5V	44.92V
	22.5Ω	5.27%	0.9854	10.2V	7.8V	44.93V

4.2 System function simulation

The input current and input voltage waveform before/after PFC is shown in Fig.4(a) and Fig.4(b). From the waveform, we can see that the input line current have significant distortion before PFC, and the input line current follows the input voltage well after PFC.

Figure 4. The input current and input voltage waveform before/after PFC

The first stage output voltage waveform without switches synchronization is shown in Fig.5 and Fig.5(b) is detail view. The simulation waveform with switches synchronization is shown in Fig.6 and Fig.6(b) is detail view. From the waveform, we may safely draw that the voltage ripple of the first stage filter capacitor without switches synchronization is 20V and the voltage ripple is 17V after switches synchronization control.

Figure 5.(a) The output voltage waveform without switches synchronization **Figure 5** (b). Detail view

Figure 6. (a)The output voltage waveform with switches synchronization **Figure 6.** (b) Detail view

The switch driving waveform of the two stage circuit without/with switches synchronization control is shown in Fig.7(a) and Fig.7(b). We can obtain all switches are on at each cycle beginning from Fig.7(a) and the switches of second stage are on when the switch of the first stage is off from Fig.7(b).

Figure 7. (a) Before switches synchronization control

Figure 7. (b) After switches synchronization control

4.3 Analysis of the input voltage and load disturbance

The output voltage waveform with load disturbance is shown in Fig.8 and Fig.9 when the input voltage is 220V and 85V. From the waveform, we can know the output voltage can quickly return the stable state when load disturb and the whole system have good effect on resisting the input voltage and load disturbance.

Figure 8. The output voltage waveform at 220V

Figure 9. The output voltage waveform at 85V

5 Conclusion

In the hybrid control strategy proposed in this paper, one cycle control algorithm based on ARM platform is applied to the double forward converter, realizing the switches synchronization control. The simulation results of system show that the power factor and the voltage ripple of filter capacitor are improved.

Reference

1. ZHANG Yan-jie. Design and implementation of single-phase active power factor correction circuit[D], Chengdou: University of Electronic Science and Technology of China.2015.
2. YANG Jing, JI Xiao-long. The two-stage PFC research based on the ML4803[J]. Telecom power technologies,2010,03:18-21.
3. YANG Fan, ZHOU Jie-min. PFC and PWM controller combo chip ML4824 and its application[J]. Power and electron technology, 2009,02:60-62.
4. YAO Xu-liang, GONG Zhan-ying. Double-barreled forward converter based on single cycle control[J]. control engineering. 2010,06:845-848.
5. The research of DC/DC converter based on one cycle control. Nanjing: The Graduate School, College of Automation Engineering, Nanjing University of Aeronautics and Astronautics,2004.
6. LING Yan-bo. A research and application on one-cycle control achieved by digital control[D]. Nanjing:The Graduate School,College of Automation Engineering, Nanjing University of Aeronautics and Astronautics, 2009.
7. ZHANG Li-juan. The research of two-stage power factor correction based on UC3854[D]. Xi'an: Xi'an University of Technology.2008.