TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.4, April 2014, pp. 2599 ~ 2605
DOI: http://dx.doi.org/10.11591/telkomnika.v12i4.5002

The Design and Simulation of Improved and Multiplex Boost Converter

Xuanfeng Shangguan*[1], Huimin Yang[2], Yongliang Wang[3], Benlong Shi[4]
[1,2,4]Electrical Engineering, Henan Polytechnic University, Jiaozuo, 454003 Henan Province, China
[3]Henan Shenhuo Gedian coal mine, Yongcheng, 476600 Henan Province, China
*Corresponding author, e-mail: shangguan_xf@163.com[1], 893086021@qq.com[2], 369811430@qq.com[3], shibenlonglh@163.com[4]

Abstract

In a MW-level and high-power wind power system, the level of current and voltage is easy to exceed the capacity of one switch device, so single boost converter has already can't meet the requirements of system. To solve this problem, for 1.2MW direct drive VSCF wind power system this paper designed a improved and multiplex boost converter, the over-voltage protection circuit branch is inserted into the circuit. The system state equation and control strategy are given, and the input current ripple is analyzed. Finally, in the Matlab environment, build the model of direct-drive wind power generation system to verify the feasibility of this circuit. The results show that: the system can run stably, has high efficiency, low ripple and has a good practical value.

Keywords: *boost converter, equation of state, control strategy, current ripple*

1. Introduction

Wind energy has become one of the renewable energy that has a very high prospect for development [1], its future is very promising, and the construction of large-scale, high-capacity wind power generation system is imperative [2]. In the direct-drive wind power system, through the generator wind energy is converted into the alternating current (AC) which amplitude and frequency change with the wind speed. This kind of alternating current will be changed into DC which amplitude still change after the three-phase uncontrolled rectifier bridge, and then the DC through the inverter will be transformed into the current that meet the requirements of power grid. But the output DC voltage of rectifier always wave in a certain range according to the generator speed [3], so it can't meet the requirements of the inverter input voltage. Therefore, we need to adopt the Boost converter in front of the inverter to increase the amplitude of the rectifier output voltage, ensure that wind power generation system can run in a wide range of wind speed.

In MW level and high-power wind power system, the current and voltage level is easy to more than the processing capacity of one switch device, so the single channel of the boost converter has already can't meet the needs of the system, in order to solve this problem, many scholars have done a lot of research at home and abroad, reference [4] using high-frequency soft-switching technology and the introduction of the current feedback, proposed an improved Boost chopper circuit. Reference [5] and [6] proposed multiple boost converter circuit on the basis of single booster converter circuit. Reference [7] discussed the multiple boost converters which is used in the 1.2MW variable speed constant frequency wind power system. Reference [8] studied the key issues of staggered and parallel chopper for direct-drive wind turbines. On the basis of many scholars' studies, in this paper, designed a multiple parallel booster converter for 1.2MW direct-drive wind power system, the main circuit adopts the three-channel parallel interlaced Boost circuit, and joined the over-voltage protection circuit in the Boost circuit, the stability of the chopper output voltage is improved. Three-channel parallel converter circuit adopts parallel method can improve the capacity of wind power system, the structure is simple, and the control is convenient and flexible, has small ripple and a good application prospect.

Received September 22, 2013; Revised October 30, 2013; Accepted November 20, 2013

2. Design of Boost Converter

DC/DC Boost converter commonly used in the direct-drive wind power generation system based on PMSG, as shown in Figure 1. The boost converter has two main functions [9]: one is tracking the maximum power of the wind energy, the other is upgraded the dc voltage to a specific value to meet the need for inverter. In a few to hundreds Kw-level of small and medium scale wind power system, the single-channel boost converter often is used. In Mw-level wind power generation systems that with low voltage (eg 690V), commonly use multiplex and parallel boost converter to solve the problems of large current [10].

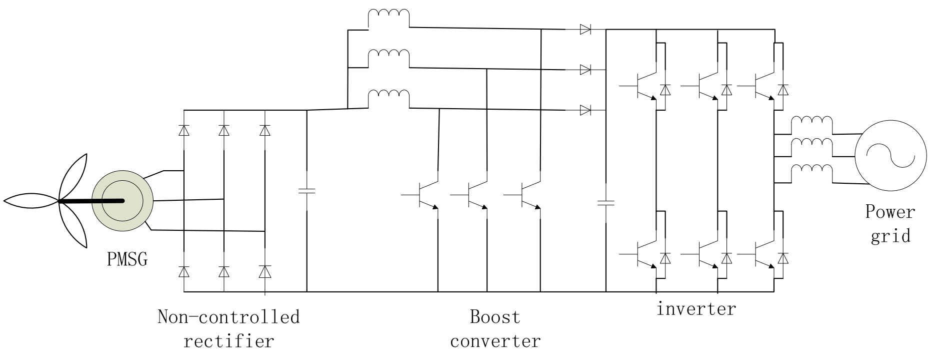

Figure 1. Non-controlled rectifier + boost converter + PWM inverter topology

In this paper, the design of boost converter circuit as shown in Figure 2, it is a three-way moral Boost converter, phase difference was 360° / N = 120° between each channel, where N is 3. The circuit actually consists of three single-channel converter in parallel, work on multiple parallel way. Each converter control signal is the same, just have Ts / 3 time delay. IGBT4 where the branch is a voltage clamping circuit, the design of this branch is mainly protect IGBT switch tube. The slip where IGBT3 in is a voltage clamp circuit, the design of this branch is mainly to protect the IGBT switches.

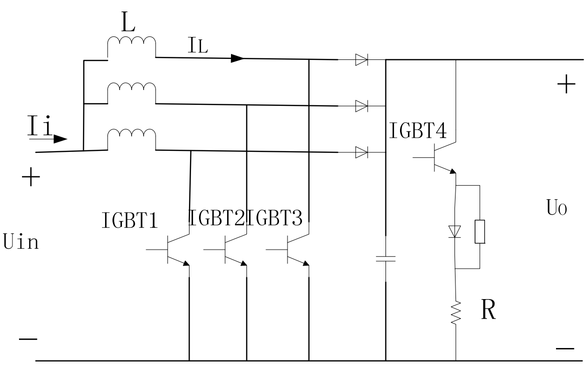

Figure 2. Multiple Parallel Boost Converter Circuit

2.1. State Equation of Boost Converter Circuit

Take single boost converter for example when analyze its state equation and made the following assumptions: 1) the switch is ideal; 2) the state transition is instantaneous; 3) Boost converter works on continuous current mode; Suppose D for inverter duty ratio, defined as D=ton/Ts; Ts was the switch cycle, ton and toff respectively, for the IGBT turn-on and turn-off time. D is changing in a dynamic process and can use lower-case d instead in the equation. Set the equivalent internal resistance of the inductor L to r in Figure 2. Corresponds with the two kinds of switch state in Boost converter circuit of IGBT, using state space average method can draw the boost converter circuit state average equation:

$$\begin{bmatrix} i_L \\ \\ \bar{u} \end{bmatrix} c^* = \begin{bmatrix} -\frac{r}{L} & -\frac{1-d}{L} \\ \\ \frac{1-d}{c} & -\frac{1}{Rc} \end{bmatrix} \begin{bmatrix} i_L \\ \\ \overline{u_c} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ \\ 0 \end{bmatrix} u_{in} \tag{1}$$

$$u_0 = u_c \tag{2}$$

When disturbance applied to the state average equations, The instantaneous value of the state quantity in formula (1) is:

$$\begin{cases} u_{in} = U_{in} + \hat{u}_{in} \\ d = D + \hat{d} \\ i_L = I_L + \hat{i}_L \\ u_c = U_c + \hat{u}_c \\ u_0 = U_0 + \hat{u}_0 \end{cases} \tag{3}$$

In formula (3) $\hat{u}_{in}$, $\hat{d}$, $\hat{i}_L$, $\hat{u}_c$, $\hat{u}_0$ respectively are the disturbance quantity of U_{in}, D , I_L , U_c , U_0 .

Take formula (3) into Equation (1) and (2), and assumes that the static volume is much larger than the dynamic component, then separated the disturbance component and the steady-state component into two groups of equations can obtain the following steady-state equation and perturbation equation:

$$\begin{cases} AX + BU_{in} = 0 \\ U_0 = F^T X \end{cases} \tag{4}$$

$$\begin{cases} \frac{d\hat{x}}{dt} = A\hat{x} + B\hat{u}_{in} + Ex\hat{d} \\ \hat{u}_0 = F^T \hat{x} \end{cases} \tag{5}$$

In formula (5) $X = \begin{bmatrix} I_L \\ U_c \end{bmatrix}$, $\hat{x} = \begin{bmatrix} \hat{i}_L \\ \hat{u}_c \end{bmatrix}$, $A = \begin{bmatrix} -\frac{r}{L} & -\frac{1-D}{L} \\ \frac{1-D}{c} & -\frac{1}{RC} \end{bmatrix}$, $B = \begin{bmatrix} -\frac{1}{L} \\ 0 \end{bmatrix}$, $E = \begin{bmatrix} 0 & \frac{1}{L} \\ -\frac{1}{c} & 0 \end{bmatrix}$, $F = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$.

Low frequency small signal dynamic state average equation of Boost converter circuit is Equation (5), from Equation (5) we can see that it is a time-invariant linear equation, transformed Equation (5) into the s domain, we can obtain the following equations:

$$\begin{cases} \hat{x} = (sI - A)^{-1} B\hat{u}_{in}(s) + (sI - A)^{-1} Ex\hat{d}(s) \\ \hat{u}_0(s) = F\hat{x}(s) \end{cases} \tag{6}$$

Considering the input voltage Uin is relatively stable, its disturbance can be ignored, according to the Equation (4) can calculate the solution of Uc, IL and D when the system is in a steady state. According to formula (6) we can calculate the open loop transfer function that the system to $\hat{d}$ is:

$$G(S)=\frac{\hat{i}_L(S)}{\hat{d}(S)}=\frac{[(SC+1/R)u_c+(1-D)i_L]/LC}{S^2+(1/RC+r/L)S+r/LRC+(1-D)^2/LC}$$
(7)

By the formula (7) can be seen that the boost converter is a second-order system, according to the derivation above can optimize the PI regulator in the Boost converter control system.

2.2. Boost Converter Control System Design

Triplicate and parallel boost converter circuit is composed of three identical single-boost converter circuit connected in parallel and connected to a load. Each boost converter circuits are adopt current-voltage double closed loop control mode. Make the triangular carrier phase shifting 2π / 3 can be obtained three times no phase shift switch frequency [11]. The outer loop control system is the boost converter circuit output voltage loop; the inner ring is the current loop that flowing through the boost choke, shown in Figure 3. Figure 4 is a voltage-limiting slip control system.

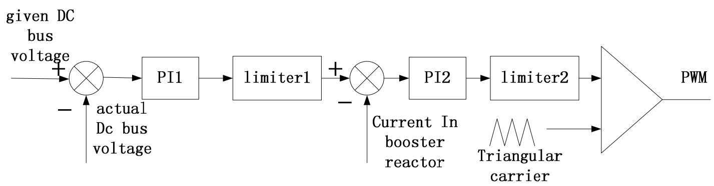

Figure 3. Control System of Boost Converter Circuit

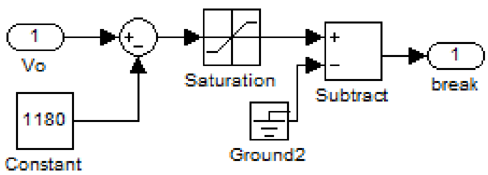

Figure 4. Control System of Voltage Limiting Branch

2.3. Optimization Design for PI Controller

$H(S)=K_P+K_I/S$ in PI regulator, according to the type (7) can be calculated G (S), the closed-loop transfer function of system is deduced as follows:

$$\hat{i}(s)=\frac{H(S)G(S)I_{ref}(s)}{1+H(S)G(S)} \quad (8)$$

According to the steady state conditions can be calculated: r=0.5Ω; L=10mH; C=7500 μF; R=1Ω; D=0.25. The system Prior transfer function is: $F(S)=H(S)G(S)$. Using the lawes criterion to determine PI controller parameters K_P, K_I that make the system stability. Based on the 1.2 MW direct drive wind power system parameters and according to the requirements of the system overshoot and adjustment time, eventually determine: K_P=1000, K_I=1.

2.4. Analysis of Current Ripple

Waveform of inductor current i_{L1}, i_{L2}, i_{L3} and total input current ii is shown in Figure 6. As can be seen from the figure, the frequency of the triple Boost converter input current ii is three times of single Boost converter.

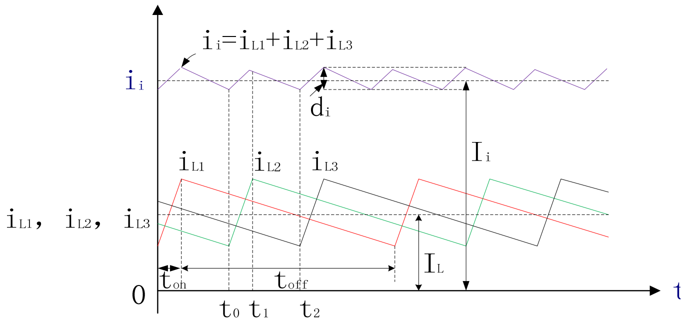

Figure 6. Current Waveform of Three-channel Multiplexed Parallel Boost Converter

First analysis 0≦D<1/3, in t_0 ~ t_1 period:

$$\Delta I_i = \Delta I_{L1} + \Delta I_{L2} + \Delta I_{L3} = \frac{1}{L}U_{in}DT - \frac{2}{L}(U_0 - U_{in})DT \quad (9)$$

Take $U_{in} = U_0(1-D)$ in formula (9) can obtain: $\Delta I_i = (1-3D)D\frac{U_0T_S}{L}$

Similarly when 1/3<D<2/3 can work out the converter input current ripple is: $\Delta I_i = \left[3D(1-D) - \frac{2}{3}\right]\frac{U_0T_S}{L}$ .When 2/3<D<1, input current ripple is: $\Delta I_i = [(3D-2)(1-D)]\frac{U_0T_S}{L}$.

Summing up, the input current ripple of triple boost converter is:

$$\Delta I_i = \begin{cases} (1-3D)D\frac{U_0T_S}{L} & 0 \le D < 1/3 \\ \left[3D(1-D) - \frac{2}{3}\right]\frac{U_0T_S}{L} & 1/3 \le D < 2/3 \\ [(3D-2)(1-D)]\frac{U_0T_S}{L} & 2/3 \le D < 1 \end{cases} \quad (10)$$

The triple Boost converter circuit input current ripple Compared with single Boost converter circuit, can get the following equation:

$$K = \begin{cases} 3 - \frac{2}{1-D} & \text{when} 0 \le D < 1/3 \\ 3 - \frac{2}{3D(1-D)} & \text{when} 1/3 \le D < 2/3 \\ 3 - \frac{2}{D} & \text{when} 2/3 \le D < 1 \end{cases} \quad (11)$$

Where K= current ripple of triple Boost converter/ current ripple of single Boost converter, as shown in Figure 7.

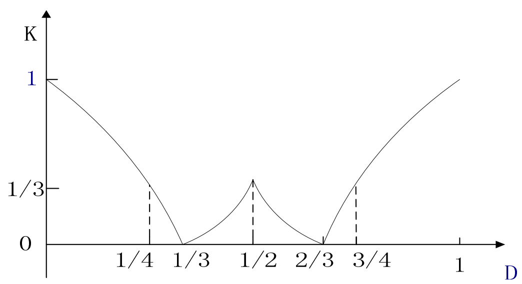

Figure 7. The Input Current Ripple Relationship between Three-channel Multiplexed Parallel Boost Converter and Single-channel Boost Converter

According to the Figure 7, we can see that the input current ripple of three-channel Boost converter was much lower than the single channel Boost converter. When duty ratio D within a certain range, can largely reduce the input current ripple, thereby using three-channel Boost converter can further reduce input/output filter sizes and costs and has a good market application value.

3. Simulation Results

In order to verify the rationality of the design, this article carried simulation experiment in the Matlab environment. Wind power system is the 1.2WM, 690V wind power system that based on PMSG, under a given wind speed, the generator runs in 0.7 times of rated speed, the input voltage Uin of Boost converter is 680V, the inductance value of three-channel converter are: L=L1=L2=L3=0.6mH, R=2Ω in clamping bar, capacitance of output filter capacitor is: C=300μF. Boost converter operating in a 2 KHz switching frequency.

Figure 8 is the output dc voltage waveform after the rectifier circuit rectifying in direct drive wind power system. Figure 9 is the output waveform after the Boost converter, from the diagram can be seen the DC voltage amplitude is 1200V and is stable, volatile small. This voltage level is necessary to inject electrical energy to 690V power grid. Figure 10 is the output waveform for the boost converter circuit that without voltage-limit branch. Figure 11 is the inverter output voltage and current waveforms. From these graphics in this paper can see that the design of multiple Boost converter can meet the requirements of the direct-drive wind power system.

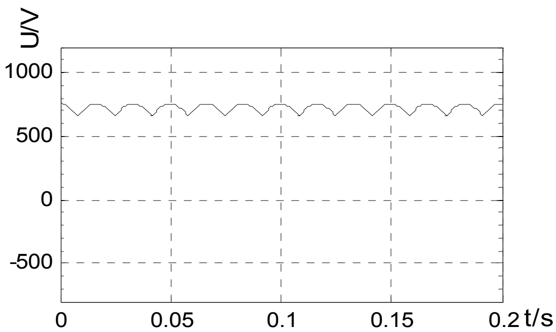

Figure 8. The Output Voltage of Rectifier

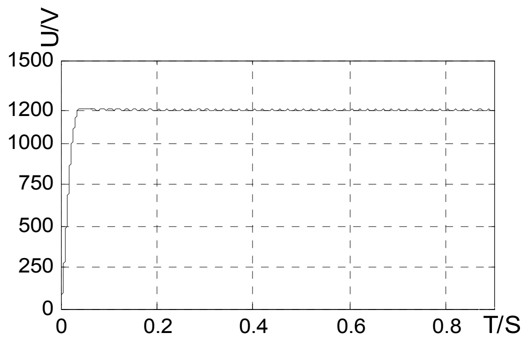

Figure 9. The Output Voltage of Boost Converter

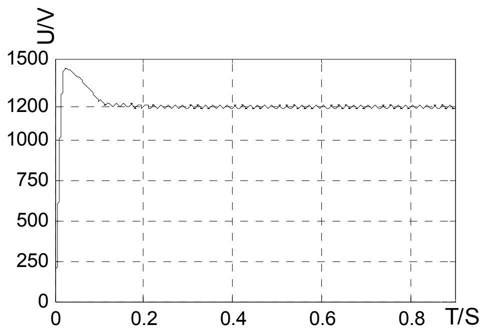

Figure 10. The Output Voltage of Unmodified Boost Converter

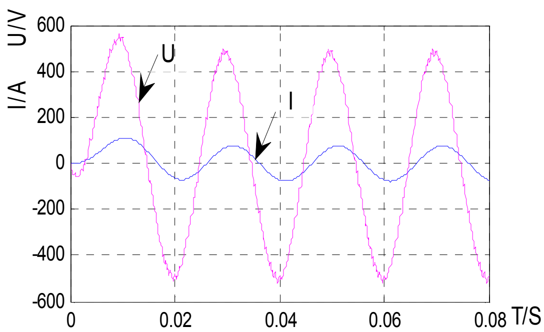

Figure 11. The Output Voltage and Current of Inverter

4. Conclusion

Based on the conventional Boost converter this paper proposed a modified Boost converter which is suitable for MW level direct-drive wind power system, the experimental results verified the theoretical analysis, also proved that the design of multiple Boost converter has advantages of small ripple, high dynamic response ability, Output voltage stability , basically can meet the requirements of direct drive wind power system, can continuously output stable voltage that inverter needs, the whole wind power system can work normally, running stably. The problem of rectifier output voltage volatile, low amplitude are effectively solved. In MW level wind power generation system will has great value in practical application.

References

[1] Zhang Cui, Shen Yanxia, Ji Zhicheng. Research on Control Strategy of Grid Inverter for Variable Speed Constant Frequency Doubly-Fed Wind Power System. *Small & Special Electrical Machines*. 2012; 40(5): 58-64.
[2] Dong Haiying, Li Shuaibing, Cao Lixin, Li Hongwei. Voltage and Reactive Power Control of Front-end Speed Controlled Wind Turbine via H Strategy. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(6): 419-424.
[3] Zhou Tianpei, Sun Wei. MPPT Method of Wind Power Based on Improved Particle Swarm Optimization. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 11(6): 73-76.
[4] Wang Zhida, Hou Yunhai, Wang Chunsheng. A Modified Booster Converter Circuit. *Journal of Shenyang Institute of Engineering (natural Science)*. 2008; 4(2): 131-132.
[5] Nakamura Yuta, *Yamamoto Masayoshi.* Optimum control design method of multi-phase trans-linked type boost chopper circuit. *IEEJ Transactions on Industry Applications*. 2012; 132(1): 121-122.
[6] Fan Shiquan, Wang Ke, Geng Li. Design and implementation of a mixed-signal boost converter with a novel multi-phase clock DPWM. *IEICE Electronics Express*. 2010; l7(14): 1091-1097.
[7] Xiong Xin, Liang Hui. Reserch on multiple chopper of MW level wind power converter system. *Power Electronics*. 2006; 40(5): 47-49.
[8] Yang GuoLiang, Li Huiguang. Reserch on the Design and Control of Staggered Parallel Boost Converter for Direct-drive Wind Power System. *Machine Tool* & *Hydraulics*. 2008; 36(8): 261-265.
[9] Chen Rong. Design and Control of Boost Chopper for Direct-drive Wind Power System. *Chinese Journal of Power Sources*. 2011; 35(12): 1568-1571.
[10] Shi Chao, Miller Brian, Mayaram Kartikeya, et. A multiple-input Boost Converter for Low-power Energy Harvesting. *IEEE Transactions on Circuits and Systems II: Express Briefs*. 2011; 58(12): 827-831.
[11] Li Jianlin. Topology and control method of Large Capacity Boost PFC for Direct-drive Wind Power System. *Transactions of China Electrotechnical Society*. 2008; 23(1):104-109.