

Research on the Control Strategy for Grid-side Converter of PWM Doubly Fed Induction Wind Power Generators

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Abstract. When the grid voltage drop, over current of transient rotor and over voltage may damage the power electronic devices. The attenuation of electromagnetic torque will lead to speed up. This paper proposes an improved feed-forward control strategy and its application in the PWM converter. When the PWM converter on voltage drops, bus voltage will be more stable. So over current problems of the DFIG rotor side can be reduced, and it also can improve voltage regulation speed of the DC bus voltage and reduce the oscillation amplitude. Furthermore, the stability of doubly fed wind generator system can be improved. The simulation results verify the validity of the modified control strategy.

1. Control strategy of PWM converter at traditional network side

The fluctuation of DC voltage bus has a direct connection with the mutation load current. When the load current is reduced, because the supply energy from rectifier is greater than that of its energy consumption, energy flow to the capacitor at DC side and charge it. It is because of this dynamic energy input and consumption imbalance caused by the DC voltage fluctuation bus. Feed-forward control can suppress the disturbance of the load current of the grid voltage, and improve the system stability[1,2].

The paper uses small signal analysis, ignores the loss of power switching devices. The output current of the rectifier input current is i_0 ; u is effective value of phase voltage and i is effective value of phase current; u_{dc} is DC voltage; reference value of inner current loop is i_{ref} ; C_{dc} is the capacitor of DC bus; Using small signal analysis to linearization the module[3]:



$$\begin{cases} u_{dc} = U_{dc} + \Delta u_{dc} \\ u = U + \Delta u \\ i = I + \Delta i \\ i_0 = I_0 + \Delta i_0 \\ i_{load} = I_{load} + \Delta i_{load} \\ i_{ref} = I_{ref} + \Delta i_{ref} \end{cases} \quad (1)$$

According to the principle of power balance and Kirchoff's current law, the power factor of the system is 1:

$$C_{de} \frac{du_{dc}}{dt} = i_0 - i_{load} \quad (2)$$

$$3ui = u_{dc}i_0 \quad (3)$$

$$i = Ki_{ref} \quad (4)$$

K is the proportional coefficient (take $K = 1/\sqrt{2}$), adding the type (1) into (2) ~ (4) type:

$$\begin{cases} C_{dc} \frac{d(U_{dc} + \Delta u_{dc})}{dt} = (I_0 + \Delta i_0) - (I_{load} + \Delta i_{load}) \\ 3(U + \Delta u)(I + \Delta i) = (U_{dc} + \Delta u_{dc})(I_0 + \Delta i_0) \\ I + \Delta i = K(I_{ref} + \Delta i_{ref}) \end{cases} \quad (5)$$

Let $\Delta u \Delta i = \Delta u_{dc} \Delta i_0 = 0$, ignore the high order term, get a transient equation:

$$\begin{cases} \Delta i_0 = \frac{3KU}{U_{dc}} \Delta i_{ref} + \frac{3KI_{ref}}{U_{dc}} \Delta u - \frac{I_0}{U_{dc}} \Delta u_{dc} \\ C_{dc} \frac{d\Delta u_{dc}}{dt} = \Delta i_0 - \Delta i_{load} \end{cases} \quad (6)$$

According to type (6), get a small signal control block diagram, as shown in Figure 1.

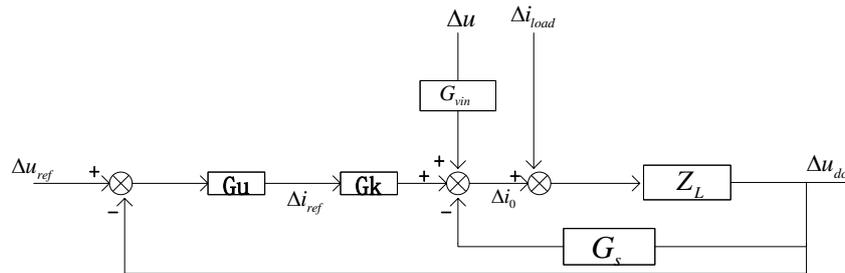


Figure 1. Small signal control charts without feed-forward control

$$\Delta u_{dc} = T_{ref} \Delta i_{ref} + T_u \Delta u + Z_0 \Delta i_{load} I_f + \Delta i_f = K_f \frac{U_{dc} (I_{load} + \Delta i_{load})}{U + \Delta u} \quad (7)$$

$$\Rightarrow I_f U + I_f \Delta u + U \Delta i_f + \Delta i_f \Delta u = K_f U_{dc} I_{load} + K_f U_{dc} \Delta i_{load}$$

$$G_u = K_p + \frac{K_1}{s}, \quad G_k = \frac{3KU}{U_{dc}}, \quad Z_L(s) = \frac{1}{sC_{dc}}, \quad G_s = \frac{I_0}{U_{dc}}, \quad G_{vin} = \frac{3KI_{ref}}{U_{dc}} \quad (8)$$

The traditional feed-forward control strategy is to feedback the change of the load current to the output of the DC bus voltage regulator[4,5], and Figure 2. is the control chart of the small signal feed forward control.

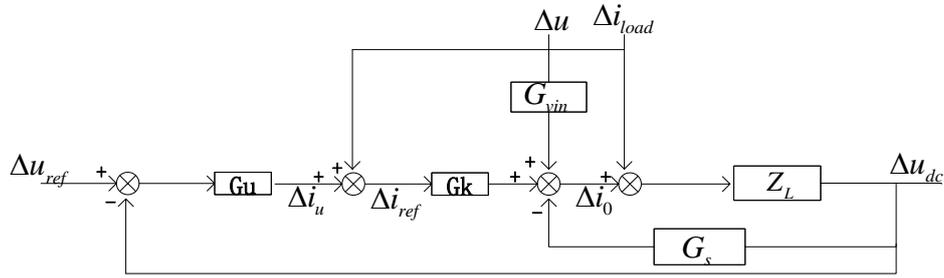


Figure2. Control block diagram with load current feed forward

According to the control block diagram 1 and Figure 2, the expression of bus voltage fluctuation and load current and power grid voltage fluctuation can be derived to this equation:

$$\Delta u_{dc} = T_{ref} \Delta i_{ref} + T_u \Delta u + Z_0 \Delta i_{load} \tag{9}$$

$$T_{ref} = \frac{\Delta u_{dc}}{\Delta i_{ref}} = \frac{G_K Z_L G_U}{G}$$

$$T_u = \frac{\Delta u_{dc}}{\Delta u} = \frac{Z_L G_{vin}}{G} \tag{10}$$

$$Z_0 = \frac{\Delta u_{dc}}{\Delta i_{load}} = \begin{cases} \frac{-Z_L}{G} & (\text{No feed - forward control}) \\ \frac{-(1-G_K) Z_L}{G} & (\text{Feed - forward control}) \end{cases}$$

$$G = 1 + Z_L (G_K G_U + G_S) \tag{11}$$

From equation (8), (9) and (10), the bus voltage from the power grid Δu and load disturbance Δi_{load} caused by fluctuations, if T_u and Z_0 are zero, theoretically speaking fluctuation of the grid voltage and load current have no impact on the bus voltage. But only can the traditional feed-forward control overcome the fluctuation of load change on the DC bus voltage to a certain extent, and the disturbance is not suppressed, T_c is not zero. Therefore, the introduction of feedback control will have a good restrain on power grid disturbance, and the stability of the system can be further improved.

2. Improved feed-forward control strategy for grid side PWM converter

The bus voltage is not affected by the load current and voltage fluctuations. It is better to lead into adaptive feed-forward control. Let T_u , Z_0 are zero, and order current into the bus capacitance is zero too, that is $i_0 = i_{load}$. The output voltage of the outer-ring is zero, that is $\Delta i_u = 0$, so the purpose of overcoming the bus voltage is achieved.

The output power of the power network is equal to the output power of the DC bus (Ignore switching losses of power devices)[6]:

$$3ui = U_{dc} i_{load} \tag{12}$$

Let $i = K i_{ref}$ the type into (11):

$$i_{ref} = \frac{1}{3K} \frac{U_{dc} i_{load}}{u} \tag{13}$$

According to the formula (12), Current inner loop parameter value is available. $i_f = K_f \frac{U_{dc} i_{load}}{u}$ ($K_f = \frac{1}{3K}$), let output of voltage outer loop is $i_u = 0$, so bus voltage is maintained at a constant value.

The analysis for feed-forward, let $i_f = I_f + \Delta i_f$:

$$I_f + \Delta i_f = K_f \frac{U_{dc}(I_{load} + \Delta i_{load})}{U + \Delta u} \tag{14}$$

$$\Rightarrow I_f U + I_f \Delta u + U \Delta i_f + \Delta i_f \Delta u = K_f U_{dc} I_{load} + K_f U_{dc} \Delta i_{load}$$

Ignore the high order term:

$$\begin{aligned} \Delta i_f &= -K_f \frac{U_{dc} I_{load}}{U^2} \Delta u + K_f \frac{U_{dc}}{U} \Delta i_{load} \\ &= -G_V \Delta u + G_I \Delta i_{load} \end{aligned} \tag{15}$$

According to the type (14), the paper get block diagram about improved feed forward control:

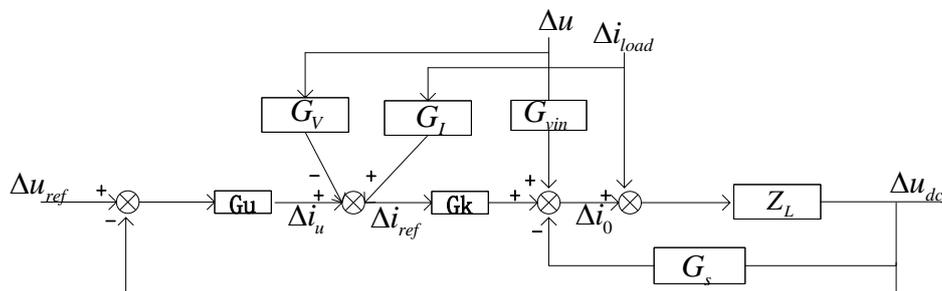


Figure 3. Block diagram about improved feed forward control

According to Figure 3, load current and disturbance of grid voltage can be expressed by using equation:

$$\Delta u_{dc} = T_{ref} \Delta i_{ref} + T'_u \Delta u + Z'_0 \Delta i_{load} \tag{16}$$

$$\begin{cases} T'_u = \frac{\Delta u_{dc}}{\Delta u} = \frac{Z_L (G_{vin} - G_V G_K)}{G} \\ Z'_0 = \frac{\Delta u_{dc}}{\Delta i_{load}} = \frac{-Z_L (1 - G_I G_K)}{G} \end{cases} \tag{17}$$

Let type (7) to type (16), T'_u , Z'_0 are zero, $\Delta u_{dc} = T_{ref} \Delta i_{ref}$. The DC bus voltage is not affected by the load current and the fluctuation of the power grid voltage in theory, and the voltage value of the DC bus is constant.

3. Simulation analysis after adding to feed-forward control

Table 1 shows the parameters about the simulation.

Table 1. Settings about the simulation parameters

$E = 220\text{V}$	$U_{dc} = 300\text{V}$	$f = 50\text{Hz}$
$L = 15\text{mH}$	$R_{load} = 200\Omega$	Switch frequency $f_{sw} = 5\text{kHz}$

There are some results when the grid voltage drop 80 percent. Grid voltage drop to 20 percent within the range of 0.2 to 0.3 sec. Voltage waveform of phase A about is shown in Figure 4. Figure 5 compares no feed-forward control to feed-forward control of current waveform of phase A. The dotted line is improved with the use of feed-forward control, the solid line is not adding the control strategy of current waveform of phase A.

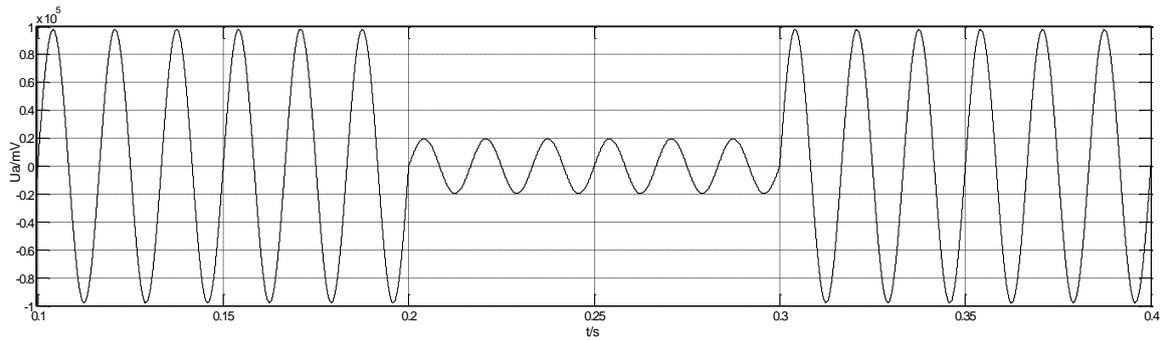


Figure4. (Within the range of 0.2 to 0.3 sec, voltage drop to 20 percent)

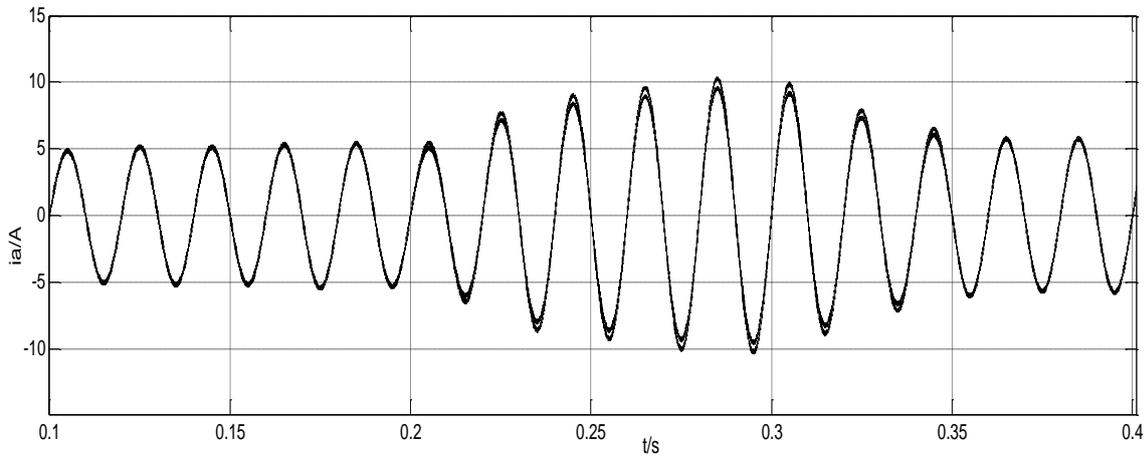


Figure5. Waveform of phase A

(--- Using of feed-forward control, —No using of feed-forward control)

According to results from the Fig.5, the improved feed-forward and feedback control has a good constrain on the voltage disturbance of the grid. When the voltage is falling, the current amplitude of the improved feed-forward control is increased.

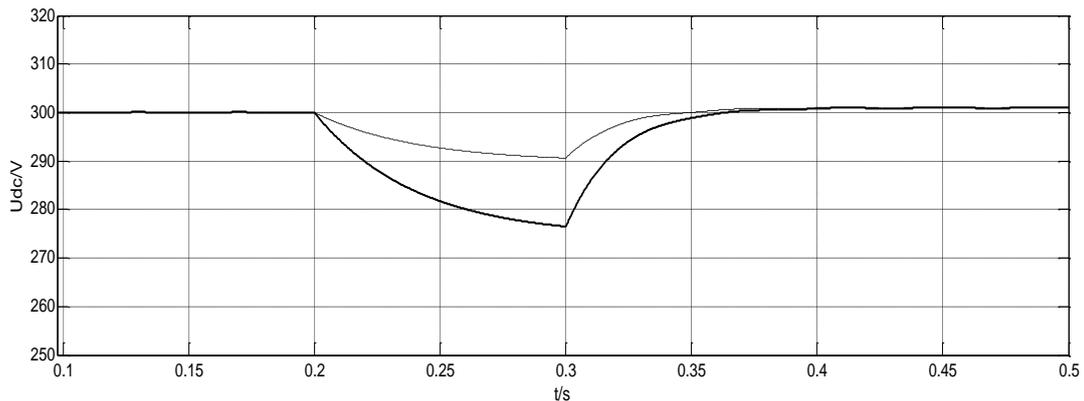


Figure6. Waveform in DC side

(--- Using of feed-forward control, —No using of feed-forward control)

According to the Figure 6, when the grid voltage drops, the DC bus voltage drop down to about 278V without adding feed-forward control. After adding the improved feed-forward control and feedback control, the DC bus voltage decreases to a minimum value of about 291V in 0.3sec. Thus, the improved feed-forward control reduces the amplitude of oscillation of DC the bus voltage and improve the response speed of the system.

4. Conclusion

When the grid voltage drops, transient rotor will appear over current and over voltage, which may damage the power electronic devices. The attenuation of electromagnetic torque will rise up the speed. The paper put forward an improved feed-forward control strategy, which apply in the PWM converter. The bus voltage will be stable when the PWM converter in voltage dropping down, which reduce the problem of over current in DFIG rotor side and improve speed on adjusting of voltage. It also can reduce the oscillation amplitude of the DC bus voltage and improve the stability of doubly fed wind generator system. Simulation results show the effectiveness of the strategy.

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