Research on the Vector Control System Based on the Difference Frequency of Wind Turbine Generator

Wanjun Zhang\textsuperscript{1, 2, 3, a}, Feng Zhang\textsuperscript{1, b}, Jingxuan Zhang\textsuperscript{1, c}, Jingyi Zhang\textsuperscript{2, d} and Jingyan Zhang\textsuperscript{2}

\textsuperscript{1}Quanzhou Institute of Information Engineering, Fujian362000, China
\textsuperscript{2}School of Mechanical Engineering, Xian Jia tong University, Shanxi710049, China
\textsuperscript{3}Lanzhou Industry and Equipment Co., Ltd., Lanzhou 730050, China
\textsuperscript{a}agszwj_40@163.com, \textsuperscript{b}zhangwanjun40@163.com, \textsuperscript{c}116543048@qq.com, \\
\textsuperscript{d}116543048@qq.com

Abstract. In order to solve the problem of wind power generator motor control system has high order, nonlinear, strong coupling and multi variable system, decoupling complex problems, based on the wind power generator slip frequency vector control that slip frequency vector control system characteristic equation, establish the generator slip frequency vector control system by using Matlab/simulink simulation. Simulation results show that the system response speed, good stability, high reliability, strong practical value.

1. Introduction

The motor of wind power generator is generally used in three-phase asynchronous motor, asynchronous motor, cage asynchronous motor, and asynchronous motor, asynchronous motor, mouse cage type asynchronous motor is more and more widely used in industry, agriculture and national defense and military intelligence unit of science and technology and other fields, in the national economy total production value dropped to 60% above. But the motor of wind power generator is usually used for asynchronous motor, and asynchronous motor is a nonlinear system, variable and multi variable coupling, compared with the general DC motor, the control system will be more complex and more difficult. In recent years, asynchronous motor technology has been widely concerned and valued by scholars all over the world. \[1\]. Asynchronous motor control adopts cross coupling and decoupling \[2, 3\], and asynchronous motor control is the key problem of motor technology at present \[4\]. In document \[5-7\], a method of applying vector control is proposed to obtain rotor flux linkage by steady-state slip ratio.

Document \[8-9\] describes in detail that the iron loss of asynchronous motors occurs mainly on the stator core. In actual operation, the iron loss will cause the rotor current and rotor flux to interfere with each other. In general, the problems of motor control system are as follows: asynchronous motor is a high order, nonlinear, strong coupling multivariable system, decoupling and complex. The wind power generator motor control system has high order, nonlinear, strong coupling and multi variable system, decoupling complex, based on the wind power generator slip frequency vector control that slip frequency vector control system characteristic equation, establish the generator slip frequency vector control system, using MATLAB simulation to control it.
2. Mathematical model of frequency difference vector control system for wind turbine generator

2.1. Wind turbine model
Because the dynamic mathematical model of induction motor is a higher order system, nonlinear, time-varying and multi coupled multivariable system, [10]. The space vector structure of the three-phase asynchronous motor is shown in figure 1:

Figure 1. Block diagram of fuzzy control.

Slip frequency vector control is the control system according to the indirect rotor flux oriented vector, without flux detection complex and cumbersome coordinate transformation, as long as the premise of ensuring the rotor flux of constant size, by detecting the stator current and the angular velocity of rotating magnetic field, through the two step the same rotating coordinate system (M-T coordinates) mathematical operation the model can realize the indirect field oriented control. The basic equations of control are as follows:

2.2. BLDCM fuzzy reference model control scheme
The BLDCM equation of motion [10] can be expressed as:

\[
\begin{bmatrix}
U_d \\
U_q \\
U_{\alpha} \\
U_{\beta}
\end{bmatrix} =
\begin{bmatrix}
L_r & 0 & L_m & 0 \\
0 & L_r & 0 & L_m \\
L_P & \omega L_m & R + L_P & \omega L_r \\
0 & L_m & 0 & L_r
\end{bmatrix}
\begin{bmatrix}
i_d \\
i_q \\
i_{\alpha} \\
i_{\beta}
\end{bmatrix}
\]

(1)

In the formula, $U_d, U_q, U_{\alpha}, U_{\beta}$ are stator and rotor on shaft voltage component, $V$; $L_s, L_r$; stator inductance, rotor inductance; $L_m$ stator and rotor inductance; $\omega$ rotor angular frequency; $\Omega$ slip angular frequency; $P$ differential operator; $R_s$ for the stator resistance, $R_r$ as the rotor resistance, $\Omega$.

The flux linkage equation is:

\[
\begin{bmatrix}
\psi_d \\
\psi_q \\
\psi_{\alpha} \\
\psi_{\beta}
\end{bmatrix} =
\begin{bmatrix}
L_r & 0 & L_m & 0 \\
0 & L_r & 0 & L_m \\
L_P & \omega L_m & R + L_P & \omega L_r \\
0 & L_m & 0 & L_r
\end{bmatrix}
\begin{bmatrix}
i_d \\
i_q \\
i_{\alpha} \\
i_{\beta}
\end{bmatrix}
\]

(2)

In the formula, $\psi_{d}, \psi_{q}$ is Stator and rotor flux excitation component, $\psi_{\alpha}, \psi_{\beta}$ stator and rotor flux linkage torque component.
Then,

$$U = \begin{bmatrix} U_a & U_d & U_a & U_d \end{bmatrix}$$

$$i = \begin{bmatrix} i_a & i_d & i_a & i_d \end{bmatrix}$$

According to the relevant knowledge of control theory, get the formula

$$R = \begin{bmatrix} R_1 & 0 & 0 & 0 \\ 0 & R_1 & 0 & 0 \\ \omega L_r & 0 & -\omega L_r & R_r \\ 0 & \omega L_m & R_1 & \omega L_m \end{bmatrix}, \quad L = \begin{bmatrix} L_1 & 0 & L_2 & 0 \\ 0 & L_1 & 0 & L_2 \\ L_2 P & L_1 & -\omega L_r & R_r \\ L_2 & \omega L_m & R_1 & 0 \end{bmatrix}$$

There

$$T_e = n_s L_r (i_d i_a + i_d i_a - i_d i_a - i_d i_a)$$

$$\begin{align*}
U_a T_s + U_d T_d + U_a T_d + U_d T_s &= U_{ref}^* - T_s \\
T_s + T_d + T_e &= T
\end{align*}$$

Described in $\alpha$ and $\beta$ coordinate systems, there are:

$$\begin{bmatrix} U_a \end{bmatrix}^T \begin{bmatrix} \alpha & \beta \end{bmatrix} \begin{bmatrix} \cos 60^\circ \\ \sin 60^\circ \end{bmatrix} T_e = \begin{bmatrix} U_d \end{bmatrix} T_s$$

$$T_e + T_s + T_a = T$$

$$\begin{align*}
T_a &= \begin{bmatrix} \frac{3}{2} U_a \end{bmatrix} - \frac{\sqrt{3}}{2} U_d \\
T_s &= \begin{bmatrix} \frac{3}{2} U_d \end{bmatrix} - \frac{\sqrt{3}}{2} U_a \\
T_e &= \begin{bmatrix} \frac{3}{2} U_a + \frac{\sqrt{3}}{2} U_d \end{bmatrix} \\
T_s &= \begin{bmatrix} \frac{3}{2} U_d + \frac{\sqrt{3}}{2} U_a \end{bmatrix}
\end{align*}$$

When $U_{ref}$ is located in other sectors, the corresponding vector action time can be obtained, and the results can be further simplified by analyzing these results:

$$\begin{align*}
X &= \frac{\sqrt{3}}{2} U_a T_a / U_d \\
Y &= \frac{3}{2} U_a + \frac{\sqrt{3}}{2} U_d T_s / U_d \\
Z &= \frac{-3}{2} U_d + \frac{\sqrt{3}}{2} U_a T_s / U_d
\end{align*}$$

$$\frac{T_s'}{T_s} = \frac{T_s'}{T}$$
For different sectors, the values of adjacent voltage space vectors $T_x$ and $T'_x$ are shown in the following table:

$$
\begin{align*}
T'_{x} &= \frac{T_x}{(T_x + T'_x)} T_x \\
T'_{x'} &= \frac{T_x}{(T_x + T'_x)} T_x \\
T'_{a} &= 0
\end{align*}
$$

Table 1. $T_x$, $T'_x$ evaluation tab

| sector number | I   | II  | III | IV  | V   |
|---------------|-----|-----|-----|-----|-----|
| $T_x$         | $-Z$| $Z$ | $X$ | $-Y$| $Y$ |
| $T'_x$        | $X$ | $Y$ | $-Y$| $-Z$| $-X$|

Tx, Ty after the assignment, but also for the judgment of the linear modulation, then judge whether the establishment of $Tx+Ty>Ts$, such as $Tx$, $Ty$ is not established, unchanged; such as the establishment of a voltage vector, the endpoint trajectory endpoint to back within two hexagon inscribed circle of non zero vector time respectively, $Tx'$ 'Ty' that is proportional to:

$$
\frac{T'_{x}}{T_{x}} = \frac{T'_{x'}}{T_{x'}}
$$

$$
\begin{align*}
T'_{x} &= \frac{T_x}{(T_x + T'_x)} T_x \\
T'_{x'} &= \frac{T_x}{(T_x + T'_x)} T_x \\
T'_{a} &= 0
\end{align*}
$$

This can then be used as the duration of the adjacent two voltage space vectors and zero vectors. Definition:

$$
\begin{align*}
T_a &= (T_a - T_x - T_x')/4 T_x \\
T_b &= T_x + T_x'/2 \\
T_c &= T_x + T_x'/2
\end{align*}
$$

In different sectors, A, B, C, three-phase corresponding switch time, T, CM1, T, cm2, T, cm3, according to the following table for assignment:

Table 2. Switch time evaluation

| sector number | I    | II   | III  | IV   | V    |
|---------------|------|------|------|------|------|
| $T_{cm1}$     | $T_a$| $T_b$| $T_c$| $T_e$| $T_b$|
| $T_{cm2}$     | $T_b$| $T_a$| $T_a$| $T_b$| $T_c$|
| $T_{cm3}$     | $T_c$| $T_e$| $T_b$| $T_a$| $T_a$|
3. Establish the control system of the slip frequency vector of wind turbines

According to (1) to (8) the structure diagram of the control system of the slip frequency vector of the wind-driven generator, as shown in figure 2.

![Figure 2. Block diagram of fuzzy control.](image)

4. Construction of slip frequency vector control system

The principle diagram of the vector control speed regulation system of the induction motor controlled by slip frequency is shown in figure 3. The main circuit of this system adopts the SPWM voltage source inverter, which is a common scheme of general frequency converter. The rotational speed adopts the slip frequency control, and the stator current frequency of the wind generator can always rise and fall synchronously with the actual speed of the rotor, so that the speed regulation is smoother.

![Figure 3. Slip frequency vector control system.](image)

5. Establishment of simulation model

According to the fuzzy control theory [12], the fuzzy control model of wind turbine generator is set up, as shown in Fig.4.
The conventional control and fuzzy control simulation of the system is carried out by using Simulink, and the result is shown in figure 7.

![Figure 4. Block diagram of fuzzy control.](image)

6. Simulation results and analysis

According to the slip frequency vector control system characteristic equation [13-14], establish the generator slip frequency vector control system, the control platform of slip frequency vector control system in the generator, control experiment platform, as shown in Figure 7, the MATLAB software is used for the control of the experimental parameters (parameters of wind turbine model) as shown in Table 1 in the simulation of constant speed startup process is 1400r/min load, prone to convergence problems, by using various calculation methods, the final selection step algorithm ode5, step E-5, the following simulation, the simulation results shown in Figure 8–11.

![Figure 5. Simulation model 1.](image)

![Figure 6. Simulation model 2.](image)

**Table 3. Motor simulation parameters**

| Simulation parameters                  | parameter values | unit  |
|----------------------------------------|------------------|-------|
| Polar logarithm                        | 2                |       |
| Stator winding resistance              | 0.435            | Ω     |
| Stator winding inductance              | 0.004            | mH    |
| Rotor winding resistance               | 0.816            | Ω     |
| Rotor winding leakage inductance       | 0.004            | mH    |
| Rotor winding acceleration             | 0.19             | Kg.m² |
| Inverter DC power supply torque        | 510              | V     |
|                                        | 0.87             | N.S   |
According to the simulation results, the speed, current, voltage and torque of the motor during starting and loading can be obtained. As you can see in Figure 8, the speed increases with time. When t=0.36s, the speed reached the rated speed of 1400 R/min or so, and when t=0.5s, as this time the motor began to load, so that the speed fluctuations, and then stabilized. Figure 10 shows that when the no-load start of the motor reaches a steady speed, the current value drops to the starting current 20A. After the motor is loaded, the current rises rapidly and then stays around. Similarly, in Fig. 9, the torque of the motor increases as it is loaded, reaching a given value Te=80 N·m. Fig. 11 ensures that the motor voltage remains constant during starting. The torque speed characteristic of the motor reflects that the motor can keep constant torque starting by vector control, and the maximum output torque can be changed by adjusting the output limit of the ASR.

The simulation and experimental results show that the induction motor speed regulation system based on slip frequency vector control has good dynamic and static control performance.
7. Summary

(1) On the basis of wind power generator slip frequency vector control that slip frequency vector control system characteristic equation, establish the generator slip frequency vector control system using MATLAB simulation to control it, to meet the wind generator motor with high speed and stable control requirements.

(2) Through the analysis of the basic principle of slip frequency vector control, using Matlab / Simulink to build the control model to realize frequency vector control of induction motor, and a type of simulation model, found that the slip frequency speed control system has fast response characteristics and dynamic characteristics should be good. Slip frequency vector control system has the advantages of simple structure and easy realization, high control precision and control performance is good, therefore, the early vector control inverter based on slip frequency control method based on vector control.

Acknowledgements

The authors thank the financial supports from National Natural Science Foundation of China(Grant no. 51165024), National key basic research development project (973 project) (2009CB724405) and New century talent support program of Ministry of Education (NCET-04-0935).

References

[1] Yano M Iwahori, Transition from slip-frequency control to vector control for induction motor of traction application [D]. Toyo University, 2010.
[2] Self-Compensation of the Commutation Angle Based on DC-Link Current for High-Speed Brushless DC Motors With Low Inductance. Fang J C, Li W Z, Li H T. IEEE Transactions on Power Electronics. 2014.
[3] Z-source inverter-based approach to the zero-crossing point detection of back EMF for sensorless brushless DC motor. Xia C L, Li X M. IEEE Transactions on Power Electronics. 2015.
[4] Precise Accelerated Torque Control for Small Inductance Brushless DC Motor. Jiancheng Fang, Xinxiu Zhou, Gang Liu. Power Electronics, IEEE Transactions on. 2013.
[5] H. Wang, W. Xu, T. Shen, G. Yang. Stator flux and torque decoupling control of induction motors with resistance adaptation. IEE Proceedings: Control Theory and Applications, 2005, 152 (4): 363-370.
[6] Hazem N Nounou, Habib-ur Rehman. Application of adaptive fuzzy control to ac machines [J]. Applied Soft Computing, 2007, (7): 899—907.
[7] Xu H J, Mirmirani M, Ioannou P A. Robust neural adaptive control of a hypersonic aircraft [C] // AIAA Guidance, Navigation, and Control conference and Exhibit. Austin, Texas: AIAA, 2003: 1–8.
[8] Yang T, Zhou L B, Li L R. Performance calculation for double sided linear induction motor with short secondary [A]. Proceeding of the 11th International Conference on Electrical Machines and Systems [C]. Wuhan, 2008: 3478—3483.
[9] Zhang Wanjun, Zhang Feng, Zhang Wanliang, et al. Fuzzy Control of Wind Turbine Based on Directional Power Conversion [J]. Electric Power Construction, 2014, 10, 35 (10): 13-16.
[10] PILAY P, KRISHNAN R. Modeling, simulation, and analysis of permanent-magnet motor drives, Part II: The brushless DC motor drive [J]. IEEE Trans on Industry Applications, 1989, 25 (2): 274-279.
[11] WeiTai, ZhangWan-jun, Zhang Yan, et al. Finite Element Analysis and Structural Optimization on the Fasteners Testing Head of Wind Power Equipment. [J]. Mechanical Research & Application, 2015, 4: 19-22.
[12] Sensorless Control of BLDC Motor Drive for an Automotive Fuel Pump Using a Hysteresis Comparator. Chun T W, Tran Q V, Lee H H, et al. IEEE Transactions on Power Electronics. 2014.
[13]  A back-EMF threshold self-sensing method to detect the commutation instants in BLDC drives. Darba A, Belie FD, Melkebeek JA. IEEE Transactions on Industrial Electronics. 2015.

[14]  Zhang Wanjun, Zhang Feng, Zhang Guohua. Research on a algorithm of adaptive interpolation for NURBS curve. [J]. Applied Mechanics and Materials, Vol. 687-691, pp.1600-1603, December 2014.