Analysis of The Influence of Flux Detector on the Subsynchronous Oscillation Characteristics of DFIG

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Abstract. There is a risk of subsynchronous oscillation after grid connection of doubly fed wind farm. The accurate detection of stator flux amplitude and phase will determine the accuracy of stator flux vector oriented control method, and then affect the subsynchronous oscillation characteristics of grid connected doubly fed wind turbine. Therefore, in PSCAD/EMTDC, this paper establishes the model of grid connected doubly fed wind turbine with u-i flux detector and u-ω flux detector respectively, and studies the influence of different flux detector on the subsynchronous oscillation. Simulation results show that different flux detector will participate in the subsynchronous oscillation to different extent.

1. Introduction
Doubly fed induction generator (DFIG) can run at variable speed and constant frequency, and can decouple the control of active power and reactive power. With the large-scale grid connection of wind power, the operation of power grid becomes more and more complex, facing the risk of subsynchronous oscillation.

At present, there are many examples of subsynchronous oscillations about doubly fed wind farms in the world. In October 2009, a grid fault occurred in Texas,, which caused a doubly fed wind farm to be connected to the grid through a 70% series-compensated line, resulting in a subsynchronous oscillation of about 20Hz[1]. A subsynchronous oscillation was also detected in the recording device of a wind power collection station in China. Analysis shows that the subsynchronous oscillation is probably caused by the internal reasons of the wind farm.

Based on the above background, it is of great significance to study the subsynchronous oscillation characteristics of doubly fed wind farms. In fact, the stator flux vector oriented control method widely used in DFIG depends on the accurate detection of the stator flux, which may affect the dynamic behavior of the system. Literature [2] pointed out that different phase-locked mechanisms and different phase-locked loop (PLL) parameters cause the wind turbine to participate in the electromechanical oscillation mode of power system in different degrees. In literature [3], the dynamic characteristics of the PLL are considered in the single machine infinite bus system. It is pointed out that the improper configuration of the PLL parameters will lead to system instability. Literature [4] show that the angle error measured by PLL will affect the power output of wind turbine. However, the
influence of different flux detector on the subsynchronous oscillation characteristics of grid connected doubly fed wind turbine has not been reported. In this paper, the mathematical models of \( u_i \) and \( u_\omega \) stator flux detector are established firstly. Then in PSCAD/EMTDC, the models of grid connected doubly fed wind turbine using \( u_i \) and \( u_\omega \) flux detectors are established respectively to verify the influence of different flux detector on the subsynchronous oscillation characteristics of grid connected doubly fed wind turbine.

2. Model of the system

Stator flux vector oriented control method

Stator flux vector oriented control method is the preferred scheme for rotor side control of doubly fed induction generator. If the stator flux is oriented on the d-axis of dq coordinate system, the d-axis and q-axis components of the stator flux are as follows

\[
\begin{align*}
\psi_{sd} &= |\psi_{sq}| = \psi_s \\
\psi_{sq} &= 0
\end{align*}
\]

(1)

Where \( \psi_{sdq} \) is the stator flux vector and \( \psi_s \) is the amplitude of \( \psi_{sdq} \).

In practical application, especially for high-power induction generator, with the increase of power, the stator winding inductance is larger and the resistance is smaller. The stator resistance voltage drop is much smaller than the total voltage drops. Therefore, the angle between stator voltage vector and flux vector can be approximately \( \pi/2 \). Under this condition, the relationship between the stator flux amplitude and the voltage amplitude is

\[
U_s = \omega L \psi_s
\]

(2)

Flux detector

At present, there are two kinds of flux detector. One is the \( u_i \) flux detector based on stator voltage and current, the other is the \( u_\omega \) flux detector based on stator voltage and grid angular frequency.

\( u_i \) flux detector. According to the relation that the induced electromotive force is equal to the rate of flux change, the flux can be obtained by integrating the electromotive force, thus the \( u_i \) flux detector can be constructed.

The stator voltage equation of doubly fed induction generator in two-phase static \( \alpha\beta \) coordinate system is

\[
\begin{align*}
u_{sa} &= R_i i_{ia} + \frac{d\psi_{sa}}{dt} \\
u_{sb} &= R_i i_{ib} + \frac{d\psi_{sb}}{dt}
\end{align*}
\]

(3)

The \( \alpha\beta \) axis component of the flux can be obtained by integrating the two sides of the above equation

\[
\begin{align*}
\psi_{sa} &= \int (u_{sa} - R_i i_{ia}) dt \\
\psi_{sb} &= \int (u_{sb} - R_i i_{ib}) dt
\end{align*}
\]

(4)

Then the amplitude and phase of the stator flux can be obtained by transforming the \( \alpha\beta \) axis component from the rectangular coordinate system to the polar coordinate system

If the stator resistance is ignored, the stator flux \( \alpha\beta \) components \( \psi_s \) and \( \psi_b \) can be obtained directly by integrating \( u_a \) and \( u_b \), and then the stator flux amplitude and phase angle can be obtained by coordinate transformation. Both the two methods need to consider the problem of eliminating the DC bias.
introduced in the integration process. Therefore, in the above two methods, the integration link is
replaced by the inertia link with a cut-off frequency of (0.5–1) Hz, so the value range of the inertia
time constant of the inertia link is (0.159–0.318) s [5].

\( u-\omega \) flux detector. According to the above, when the stator flux was oriented, if the stator resistance is ignored, the amplitude of the stator flux is constant

\[
\psi_s = \frac{U_s}{\omega_t}
\]

and the phase angle of stator flux lags behind the phase angle of stator voltage \( \pi/2 \). After Clarke transformation and transformation from rectangular coordinate system to polar coordinate system, the amplitude and phase of stator voltage can be obtained. The phase of stator flux can be obtained by subtracting \( \pi/2 \) from the phase of stator voltage, and the amplitude of stator flux can be obtained by dividing the amplitude of stator voltage by the grid angular frequency. The grid angular frequency can be obtained by PLL. The dynamic performance of PLL is determined by \( K_p \) (the proportional gain) and \( K_i \) (the integral gain) of PI link in PLL, so this parameter will have an impact on the dynamic performance of flux detector and even the grid connected doubly fed wind turbine.

3. Simulation analysis

Introduction to simulation model
In the model established in this paper, the grid side converter adopts the grid voltage vector oriented control method, the rotor side converter adopts flux vector oriented control method. The model of grid connected doubly fed wind turbine is shown in Figure 1. \( R_L \) and \( X_L \) represent the resistance and reactance of transmission line, \( R_S \) and \( X_S \) represent the equivalent resistance and reactance of the grid.

![Figure 1. Model of grid connected doubly fed wind turbine.](image)

3.1. The case of \( u-i \) flux detector

3.1.1. Ignore stator resistance. Under the condition of wind speed of 11.5m/s and rotating speed of 0.984pu, the frequency spectrum of the active power of the doubly fed wind turbine is shown in Figure 2(a). It can be seen from the figure that there is no obvious subsynchronous oscillation component in the active power.

In order to observe the influence of the time constant \( T \) of the internal inertial link of the flux detector, change the value of \( T \) within its range, and draw the curve of the frequency and amplitude of subsynchronous oscillation, as shown in Figure 2(b), (c). It can be seen from the figure that the change of inertia time constant of stator flux detector has no obvious influence on the frequency and amplitude of subsynchronous oscillation.
3.1.2. Do not ignore stator resistance. Under the condition of wind speed of 11.5m/s and rotating speed of 0.984pu, the frequency spectrum of the active power of the doubly fed wind turbine is shown in Figure 3(a). It can be seen from the figure that the active power contains subsynchronous oscillation component near 47Hz, but the amplitude is very small, less than 2kW. In this case, change the value of T within its range, and draw the curve of frequency and amplitude of subsynchronous oscillation, as shown in Figure 3(b), (c). It can be seen from the figure that the change of the inertia time constant has no obvious influence on the frequency and amplitude of the subsynchronous oscillation.

3.2. The case of u-ω flux detector

The phase angle of the flux is obtained by directly calculating the measured signal, and the flux amplitude is obtained by dividing the grid voltage amplitude by the grid angular frequency measured by PLL in u-ω flux detector. Next, $K_p$ and $K_i$ of PI link in PLL are changed under the condition of ensuring the normal operation of PLL and the system, the frequency spectrum of active power is carried out under the condition of wind speed of 11.5m/s and rotating speed of 0.984pu. Set the value of $K_p$ to 0.5 and leave it unchanged, and increase $K_i$ from 4 to 8 in steps of 0.5. Fig. 4 shows the curve of frequency and amplitude of subsynchronous oscillation when $K_i$ changes. It can be seen from the figure that the frequency remains unchanged and the amplitude has no obvious tendency to change.
Set the value of $K_i$ to 333 and leave it unchanged, and increase $K_p$ from 60 to 84 in steps of 4. Fig. 5 shows the curve of frequency and amplitude of subsynchronous oscillation when $K_p$ changes. It can be seen from the figure that the frequency remains unchanged and the amplitude has no obvious tendency to change.

In conclusion, under the existing system parameters and operation conditions, the change of PI parameters of PLL does not affect the sub synchronous oscillation characteristics of the system.

4. Conclusion
Through the above simulation, the following conclusions are obtained:

(1) For the doubly fed wind turbine with stator flux vector oriented control method on the rotor side, the subsynchronous oscillation characteristics of the system are different when different flux detectors are used.

(2) When the u-i flux detector ignoring the stator resistance is adopted, the subsynchronous oscillation component is very small, while the sub synchronous oscillation component can be observed when the stator resistance is not ignored. Changing the parameters of the u-i flux detector has no obvious effect on the subsynchronous oscillation.

(3) When the u-ω flux detector is used, the subsynchronous oscillation component of the system is larger than that of the u-i flux detector. Under the same operating condition, the u-ω flux detector has larger influence on the subsynchronous oscillation.
(4) The integral gain and the proportional gain of the PI link of the PLL in the u-ω flux detector do not have an obvious effect on the subsynchronous oscillation.

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