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Stability of Doubly-Fed Induction Generator under Stator Voltage Orientated Vector Control

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ABSTRACT-

This paper investigated the effect of tuning parameters. It gives the variation in the tuning parameters of PI-controller and adjusts the stability of doubly-fed induction generator. Tuning parameters are represented in terms of natural frequency and damping ratio. The dynamic response of the system is determined by the value of the damping ratio. The impact of the damping ratio on the tracking behaviour of the system is examined. The results indicate that when the damping ratio is increased, the overshoot decreases in the case of a step change in the reference current. Up to a point, this is a classical response of a second order system. However, even for damping ratios equal or larger than one there is an overshoot. Also, with an increasing damping ratio, the rise time decreases. In the following analysis, where the stability of the DFIG vector control in an SVO is examined .Tuning parameters are calculated at different value of damping ratio (ζ=0.4, 0.7, 1.0, 1.3) .Thus system is stable at damping ratio =0.7.

Key words - DFIG, Stability, SVO

I. INTRODUCTION

The stability of a doubly-fed induction generator under vector control in stator voltage orientation is investigated. The inner current loop dynamics can be neglected when an stator voltage orientation is employed. As a result, the poorly damped poles of the doubly- fed induction generator system were considered unaffected by the inner current loop tuning. Doubly-fed induction machines are currently the preferred topology for wind turbine applications. In contrast to the fixed speed induction generator topology, they provide the capability of independent control of their active and reactive power output. Many low-power wind turbines built to-date were constructed according to the “Danish concept” (Figure), in which wind energy is transformed into electrical energy using a simple squirrel-cage induction machine directly connected to a three-phase power grid. The rotor of the wind turbine is coupled to the generator shaft with a fixed-ratio gearbox. Some induction generators use pole-adjustable winding configurations to enable operation at different synchronous speeds.

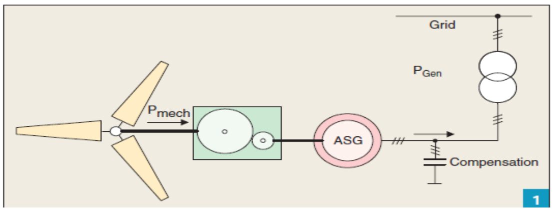

Fig.1 Fixed speed “Danish” concept

The construction and performance of fixed-speed wind turbines very much depends on the characteristics of mechanical sub circuits, e.g., pitch control time constants, main breaker maximum switching rate, etc. The response time of some of these mechanical circuits may be in the range of tens of milliseconds. As a , each time a gust of wind hits the turbine, a fast and strong variation of electrical output power can be observed. These load variations not only require a stiff power grid to enable stable operation, but also require a sturdy mechanical design to absorb high mechanical stresses. This strategy leads to expensive mechanical construction, especially at high-rated power.

Modern high-power wind turbines are capable of adjustable speed operation. Key advantages of adjustable speed generators compared to fixed-speed generators are:

(1)They are cost effective and provide simple pitch control; the controlling speed of the generator (frequency) allows the pitch control time constants to become longer, reducing pitch control complexity and peak power requirements. At lower wind speed, the pitch angle is usually fixed. Pitch angle control is performed only to limit maximum output power at high wind speed.

(2) They reduce mechanical stresses; gusts of wind can be absorbed, i.e., energy is stored in the mechanical inertia of the turbine, creating an “elasticity” that reduces torque pulsations.

(3) They dynamically compensate for torque and power pulsations caused by back pressure of the tower. This back pressure causes noticeable torque pulsations at a rate equal to the turbine rotor speed times the number of rotor wings.

(4)They improve power quality; torque pulsations can be reduced due to the elasticity of the wind turbine system. This eliminates electrical power variations, i.e., fewer flickers.

(5) They improve system efficiency; turbine speed is adjusted as a function of wind speed to maximize output power. Operation at the maximum power point can be realized over a wide power range. As a result, energy efficiency improvement up to 10% is possible.

(6) They reduce acoustic noise, because low-speed operation is possible at low power conditions.

The various vector control schemes can be divided into two broad subcategories depending on the orientation of the synchronously rotating dq0 reference frame:

(1) Stator flux orientation, where the d-axis is aligned to the stator flux vector

(2) Stator voltage orientation, where the q-axis is aligned to the stator voltage vector

When a stator flux orientation is employed, there is a limit on the magnitude of the machine’s reactive power production beyond which the machine becomes unstable. Thus, stability problems do not exist when an SVO is employed.

The inner current loop dynamics are taken into account and the impact of the tuning of the PI controllers on the stability of the DFIG is investigated. Instead of following a specific tuning methodology, a generalised approach is followed. The tuning of the inner current loop is regarded as a two-dimensional problem with the proportional and integral gains of the PI controllers, being independent variables. Both the mathematical analysis and simulations reveal that with erroneous tuning of the PI controllers the DFIG can become unstable in SVO vector control.

II. LITERATURE SURVEY

A. the DFIG wind Turbine

Doubly fed induction generator with a four-quadrant ac-to-ac converter based on insulated gate bipolar transistors connected to the rotor windings. The DFIG is constructed from a wound rotor asynchronous machine. Variable speed operation is obtained by injecting a variable voltage into the rotor at slip frequency The injected rotor voltage is obtained using two AC/DC insulated gate bipolar transistor based voltage source converters , linked by a DC bus. The converter ratings determine the variable speed range. Using the DFIG approximate equivalent circuit model shown in Fig. 2 the effect of injecting additional rotor voltages on the steady state characteristics can he observed.

With increased penetration of wind power into electrical grids, DFIG wind turbines are largely deployed due to their variable speed feature and hence influencing system dynamics. This has created an interest in developing suitable models for DFIG to be integrated into power system studies. The continuous trend of having high penetration of wind power, in recent years, has made it necessary to introduce new practices. For example, grid codes are being revised to ensure that wind turbines would contribute to the control of voltage and frequency and also to stay connected to the host network following a disturbance. In order to achieve constant switching frequency, Calculation of the required rotor voltage that must be supplied to the generator is adopted. Various methods such as hysteresis controller, stationary PI controller and synchronous PI Controller have been adopted in order to control current-regulated induction machine. Among which, synchronous PI controller has been acknowledged as being superior.

Power quality is actually an important aspect in integrating wind power plants to grids. This is even more relevant since grids are now dealing with a continuous increase of non-linear loads such as switching power supplies and large AC drives directly connected to the network. By now only very few researchers have addressed the issue of making use of the built-in converters to compensate harmonics from non-linear loads and enhance grid power quality. In, the current of a non-linear load connected to the network is measured, and the rotor-side converter is used to cancel the harmonics injected in the grid. Compensating harmonic currents are injected in the generator by the rotor-side converter as well as extra reactive power to support the grid. It is not clear what are the long term consequences of using the DFIG for harmonic and reactive power compensation .some researchers believe that the DFIG should be used only for the purpose for which it has been installed, i.e., supplying active power only .

B. Speed control of optimum power

Wind turbines operate by extracting energy from the wind .The available energy in a wind stream is given as:

$$P_{air} = \frac{1}{2}\rho A U^{3}$$

ρ = air density.

A = area swept by wind turbine blades.

U = wind turbine speed.

The energy which can be extracted by the wind turbine is less than the energy in the wind. Speed ratio (ƛ) which is the ratio between the velocity of the rotor tip and wind speed defined by:

$$\lambda = \frac{w_r R}{U}$$

w_r = aerodynamic rotor speed.

R= radius of the rotor.

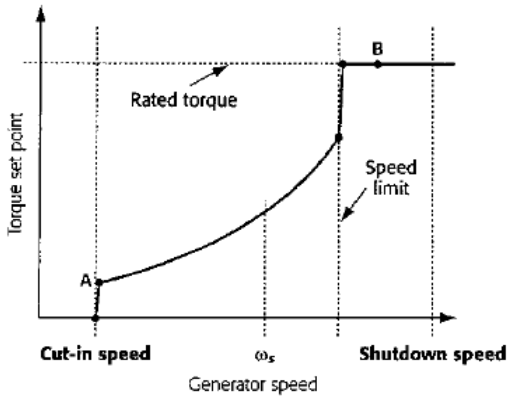

Fig.2 Torque speed characteristic for turbine control strategy

To extract the maximum power from the wind, the rotor speed should vary with the wind speed, maintaining an optimum tip speed ratio.

In a practical DFIG wind turbine the rotor torque is used as a set point reference. Atypical set point torque - speed characteristic applied for controlling DFIG wind turbines .The cut-in and rated speed limits are mainly due to converter ratings although the upper rotational speed may also be limited by an aerodynamic noise constraint.

C. Control of DFIG wind turbine

In the configuration shown, the rotor side converter (C l) is used for both speed control and for power factor and/or voltage control. Converter C2 acts to transmit real power only.

The generator control is based on a d q coordinate system, where the q component of the stator voltage is selected as the real part of the bus bar voltage and **d** component is the imaginary part.

DFIG wind turbine voltage control strategy is typically defined to provide power factor control of the induction generator, using converter C1. Terminal voltage control can also be provided through the rotor side converter. However, reactive power injection can be obtained from either the rotor side converter (C1) or the stator side converter (C2).

D. System frequency control

Power system, frequency is controlled by balancing the generation of power against load demand on a second-by-second basis. There is a need for continuous adjustment of generator output as the load demand varies as well as an ability to respond to occasional larger mismatches in generation and load Caused, for example, by the tripping of a large generator or a large load.

In normal operation the system frequency is controlled within 49.8 - 50.2Hz and a number of the generators operate to provide continuous response to frequency changes within this range

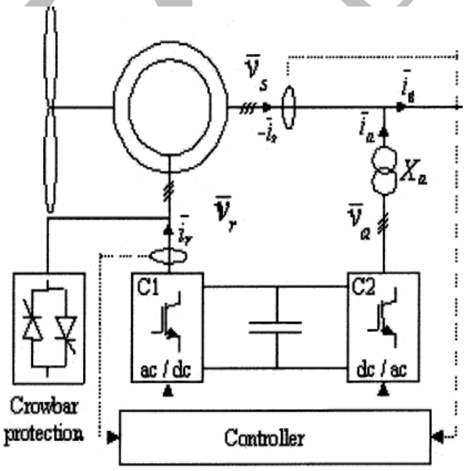

Fig.3 Basic configuration of a DFIG wind turbine

. Automatic frequency control by a generating unit is normally achieved by operating the turbine on a droop characteristic. For example if the power system frequency drops, input power to the turbine is increased proportionately by the droop gain. The increase in the output power maintains the balance between the total generation and the load, and the system will reach equilibrium at a slightly reduced frequency this action takes place continuously so the turbine power output is changed in real time to match the load changes and the system frequency remains within allowable limits.

III. PROBLEM FORMULATIONS

A. Mathematical model of DFIG

The T-equivalent circuit of the doubly fed induction generator in synchronous coordinates is shown in figure (3) Based on the equivalent circuit, the mathematical model of the DFIG is obtained by applying the Kirchhoff‵s voltage law in stator side and rotor side. $V_{ds} = -R_s I_{ds} - w_s \psi_{qs} + \frac{d\psi_{ds}}{dt}$ (a)

$$V_{qs} = -R_s I_{qs} + w_s \psi_{ds} + \frac{d\psi_{qs}}{dt} \qquad \text{(b)}$$

$$V_{dr} = R_r I_{dr} - (w_s - w_r)\psi_{qr} + \frac{d\psi_{dr}}{dt} \qquad \text{(c)}$$

$$V_{qr} = R_r I_{dr} + (w_s - w_r)\psi_{dr} + \frac{d\psi_{qr}}{dt} \qquad \text{(d)} \quad \psi_{ds} = -L_{ss} I_{ds} + L_m I_{dr} \qquad \text{(e)}$$

$$\psi_{qs} = -L_{ss} I_{qs} + L_m I_{qr} \qquad \text{(f)} \quad \psi_{dr} = L_{rr} I_{dr} - L_m I_{ds} \qquad \text{(g)}$$

$$\psi_{qr} = L_{rr} I_{qr} - L_m I_{qs} \qquad \text{(h)} \quad L_{ss} = L_s + L_m \qquad \text{(i)} \quad L_{rr} = L_r + L_m$$

(j)

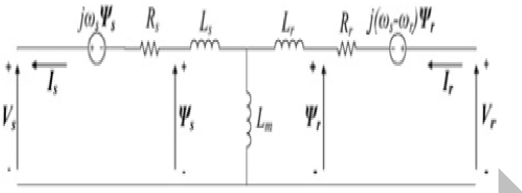

Fig.4 T-equivalent of DFIG

V_{ds} = d-axis stator voltage, V_{qs} = q-axis stator voltage

V_{dr} = d-axis rotor voltage, V_{qr} = q-axis rotor voltage

ψ_{ds} = d-axis stator flux linkage, ψ_{qs} = q-axis stator flux linkage

ψ_{dr} = d-axis rotor flux linkage, ψ_{qr} = q-axis rotor flux linkage

I_{ds} = d-axis stator current, I_{qs} = q-axis stator current

I_{dr} = d-axis rotor current, I_{qr} = q-axis rotor current,

R_s = stator resistance, R_r = rotor resistance,

L_m = magnetising inductance, L_s = stator leakage inductance

L_r = rotor leakage inductance, L_{ss} = stator self-inductance,

L_{rr} = rotor self-inductance, w_s = synchronous frequency

w_r = rotor electrical frequency.

B. Main loop tuning based on the reduced order representation

The transfer function of the simplified system is written as

$$F(s) = \frac{k_P s + k_I / w_b}{L_{\sigma r} s^2 + (R_r + k_P)s + (k_I / w_b)}$$

General second order system is express in terms of natural frequency and damping ratio

$$F(s) = \frac{(2L_{\sigma r}\xi w_n - R_r)s + L_{\sigma r} w_n^2}{L_{\sigma r}(s^2 + 2\xi w_n s + w_n^2)}$$

Comparing between both equations, obtaining the tuning parameters in term of natural frequency.

$$k_I = L_{\sigma r} w_b w_n^2$$

$$k_p = 2L_{\sigma r}\xi w_n - R_r$$

IV. RESULTS

This paper investigated the effect of tuning parameters. Tuning parameters are expressed in terms of natural frequency and damping ratio. The stability of the system is determined by the value of the damping ratio. Damping ratio control the stability of DFIG system. In the simulink analysis, where the stability of the DFIG vector control in an SVO is checked. Tuning parameters are calculated. Thus system is stable at damping ratio =0.7.

V. FUTURE PLAIN

In this paper, this investigated the stability of DFIG. Future work is done to make the more stable as contrast to this paper.

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