36.7 Model of a Wind Turbine with a Synchronous Generator

The general structure of a model of a variable-speed wind turbine with a synchronous generator (Type IV) is depicted in Figure 36.11. In this section we will only discuss the generator model, the converter model, the rotor speed controller model and the voltage controller model. The wind speed model is identical to that for the fixed-speed turbine, which is described in Section 36.5.2, and the rotor model and pitch angle controllers are identical to those used in the doubly fed induction generator which were described in Sections 36.6.3 and 36.6.8.

The protection system of a wind turbine with a doubly fed induction generator is different from that of a turbine with a synchronous generator and full-scale frequency converter. However, because of the simplifying assumptions used in models for dynamic simulations, the discussion in Section 36.6.6 also holds for the model of the protection system of a synchronous generator wind turbine. As with the other wind turbine models, the grid model will not be discussed.

36.7.1 *Generator Model*

The shaft of a turbine with a synchronous generator can be represented by a lumped mass model, which is described in Equation (36.32), instead of a two- mass model. This is because the mechanical and electrical parts, to a large extent, are decoupled by the power electronics in variable-speed wind turbines, just as in the case of a doubly fed induction generator turbine. Equation (36.32) is considered as part of the synchronous generator model.

Using a standard dq-coordinate system, the electrical equations for a wound rotor synchronous generator can be written (Kundur, 1994) as

$$u_{ds} = -R_s i_{ds} - \omega_r \psi_{qs} + \frac{d\psi_{ds}}{dt}, \quad (36.44)$$

$$u_{qs} = -R_s i_{qs} + \omega_r \psi_{ds} + \frac{d\psi_{qs}}{dt}, \quad (36.45)$$

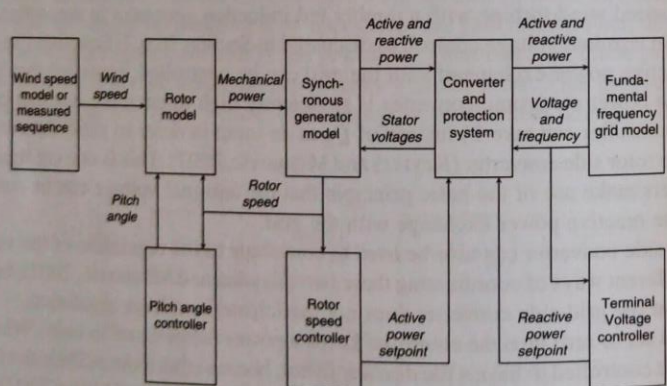

Figure 36.11 Generator structure of a model of a variable-speed wind turbine with synchronous and a generator full-scale frequency converter (Type IV)

$$u_{fd} = R_{fd} i_{fd} + \frac{d\psi_{fd}}{dt}, \quad (36.46)$$

where the subscripts fd indicate field winding quantities.

Considering the assumptions in Section 36.4, the relationship between the currents i and flux linkages ψ are described by

$$\psi_{ds} = -(L_{ls} + L_{dm}) i_{ds} + L_{dm} i_{fd}, \quad (36.47)$$

$$\psi_{qs} = -(L_{ls} + L_{qm}) i_{qs}, \quad (36.48)$$

$$\psi_{fd} = L_{fd} i_{fd} - L_{dm} i_{ds}. \quad (36.49)$$

All quantities here are in per unit.

In the case of a permanent magnet rotor, the expressions for u_{fd} and ψ_{fd} in Equations (36.46), (36.47) and (36.49) disappear because they refer to field winding quantities, and the expression for ψ_{ds} in Equation (36.47) becomes

$$\psi_{ds} = -(L_{ls} + L_{dm}) i_{ds} + \psi_{pm}, \quad (36.50)$$

in which ψ_{pm} is the flux linkage provided by the permanent magnet mounted on the rotor which is coupled to the stator winding.

When neglecting the $d\psi_s/dt$ terms in the stator voltage equations, the voltage–flux relationships become

$$u_{ds} = -R_s i_{ds} + \omega_r (L_{ls} + L_{qm}) i_{qs}, \quad (36.51)$$

$$u_{qs} = -R_s i_{qs} - \omega_r [(L_{ls} + L_{dm}) i_{ds} + L_{dm} i_{fd}], \quad (36.52)$$

$$u_{fd} = R_{fd} i_{fd} + \frac{d\psi_{fd}}{dt}. \quad (36.53)$$

The $d\psi_s/dt$ terms in the expressions for u_{ds} and u_{qs} are neglected because the associated time constants are small, and taking them into account would require the development of a detailed representation of the power electronic converter, which includes high-frequency phenomena in which we are not interested here. A more detailed model of the converter has been given by Chen and Spooner, 2001.

The electromechanical torque is given by

$$T_e = \psi_{ds} i_{qs} - \psi_{qs} i_{ds} \quad (36.54)$$

and the equation of motion is given by Equation (36.32) or the equations in Section 36.5.4. The active and reactive power of a synchronous generator are given by

$$P_s = u_{ds} i_{ds} + u_{qs} i_{qs}, \quad (36.55)$$

$$Q_s = u_{qs} i_{ds} - u_{ds} i_{qs}. \quad (36.56)$$

It should be pointed out that the generator is fully decoupled from the grid by the power electronic converter. Therefore, the power factor of the generator does not affect the reactive