Reduction of flicker effect in wind power plants with doubly fed machines

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Abstract. Changes and pulsations in the active and reactive powers generated by wind turbines due to wind speed variations and tower shadow effect may cause serious problems in operation of isolated or distant areas of power grids. Particularly resulting flicker effect may deteriorate power quality in connected power networks. Use of doubly fed machines with suitable control method may substantially reduce impacts of these phenomena. Vector control of doubly fed machines is analyzed and discussed in the paper with respect to the compensation of varying mechanical torque produced by wind turbines. Properties of power units with induction generators and doubly fed machines are compared.

Key words

Wind turbines, flicker, induction generators, doubly fed machines, vector control.

1. Introduction

The international oil crisis in 1972 initiated a restart of the utilization of renewable energy resources on a large scale, wind power, among others. Percentage of electrical power generated in wind power plants is rapidly growing every year all over the world and, thus, the impact of such plants on the power grid is becoming increasingly important. The connection of wind turbines on the distribution network may affect grid power quality. This is the reason why so much attention has recently been paid to the issues associated with operation of wind turbines in power systems. One of the most important power quality problems caused by wind power plants are large fluctuations of generated power due to varying wind speed and due to the construction of the wind turbine itself [1-4]. Particularly quick changes of mechanical power with so called 3*p*-frequency in the case of a three-blade turbine at the input of the generator, so called tower shadow effect, contribute very much to the flicker effect in weak or rural power grids, which introduces an additional limit on the wind energy utilization in such power networks.

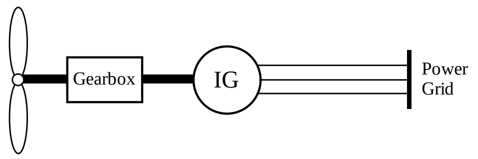
Energy efficiency of wind turbines may be much increased by the introduction of variable-speed generation units. One of perspective solutions is the use of doubly fed machines. Such machines provide significantly improved control capabilities over a relatively narrow speed range around the synchronous speed. The solid-state converter supplying the rotor winding of the doubly fed machine is rated at a mere fraction of the nominal power of the generator depending on the required speed range.

On the other hand, however, construction of the doubly fed machine is more complicated than that of the induction machine as it contains slip rings in the rotor windings and brushes. The present paper concerns with operation of wind turbines with induction generators and doubly fed machines. The attention is given mainly to the effect of these power units on the flicker in the power grid and compares operating properties of both systems based on numerical simulation results.

2. Systems under investigation

Operation of both power units with induction machines and doubly fed machines have been investigated. In the first considered system in Fig. 1*a*, the stator of the induction machine is connected to the power grid directly. The machine is mechanically driven by a wind turbine, which is typically connected by means of a gearbox in order to achieve higher angular velocity of the electric machine.

The amount of the generated electrical power is given by the difference between the mechanical and synchronous speeds of the machine and depends, therefore, very much on the wind speed. All the magnetizing energy for the induction machine needs to be taken from the power network in the form of reactive power.



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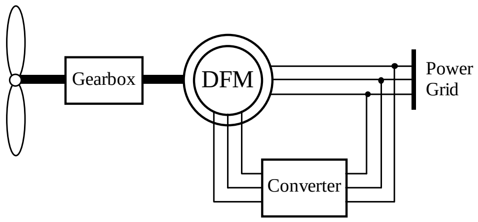


b)

Fig. 1. Systems under investigation.

The scheme of the second considered system with the doubly fed machine is depicted in Fig. 1*b*. The stator winding of the machine is connected to the power grid directly as in the previous case. However, the currents in the rotor winding can be controlled by the electrically connected solid-state converter, which allows much improved control of stator currents. The input power needed for the function of the converter is drawn from the power grid.

Stable operation of the second considered system can be achieved only by suitable control of rotor currents of the machine. The vector control method in the synchronous reference frame is considered throughout this paper [5 - 8]. A simplified scheme of the employed vector control is shown in Fig. 2. This scheme was modified in order to control the entire active power generated by the power unit by compensating the power consumed or generated by the rotor of the machine.

3. Numerical simulation

Numerical models of both the systems under investigation have been developed in the Simulink program. The parameters of a 100 kW machine have been used in the simulation. In order that all the considered systems could be compared in similar operating modes, the same course of mechanical speed was enforced in simulations. The speed was varied sinusoidally by 1% with the frequency of 1 Hz around the constant value of 101.5% of the synchronous speed. Thus, the machine always ran at supersynchronous speed in this case. All the electrical quantities are computed in per unit system.

First, operation of the system with the induction machine was simulated and investigated, Fig. 3. Figure 3a) shows the components of stator currents i_s in α (solid line) and β (dotted line) axes and the components of rotor currents i_r in *d* (solid line) and *q* (dotted line) axes. It can be noted that the variation of mechanical speed by 1% results in much bigger variation in the amplitudes of the stator currents reaching some 50%. The same variation can be observed in the waveform of the active electrical power p_c generated by the machine in Fig. 3b). The power p_r supplied to the rotor by an external source is zero in the case of an induction machine. Figure 3c) shows the enforced mechanical angular velocity ω_m and the electromagnetic torque T_e produced by the machine.

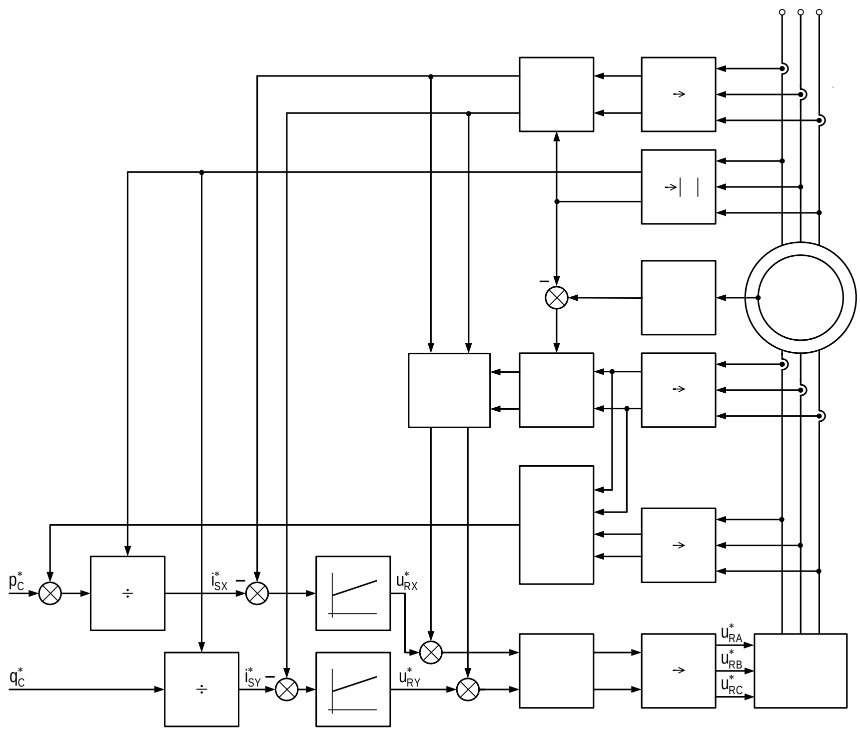


Fig. 2. Vector control scheme.

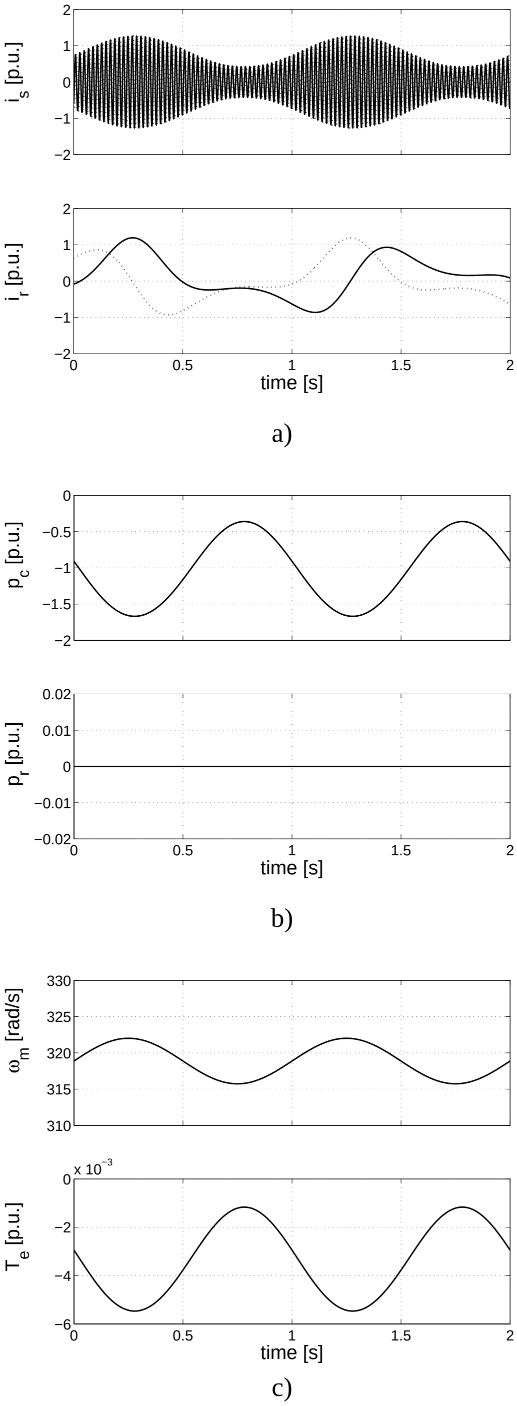


Fig. 3. Operation of unit with induction machine.

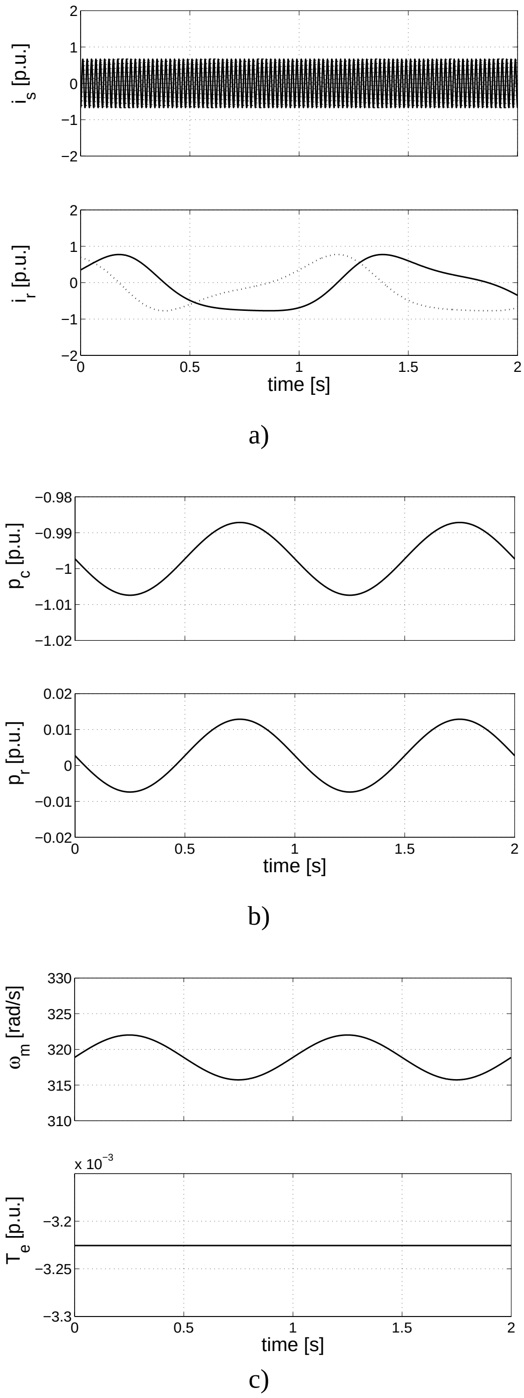
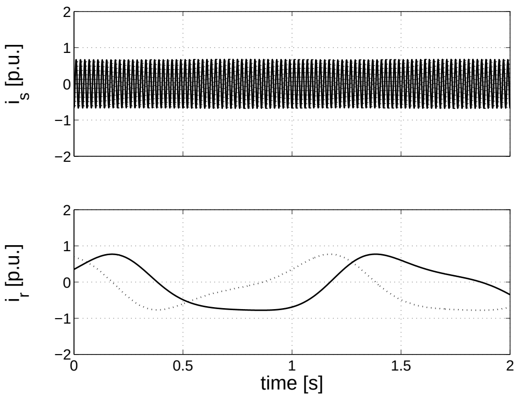


Fig. 4. Operation of unit with doubly fed machine – conventional control.

Second, the power unit with doubly fed machine with stator currents regulated by a conventional vector controller was considered, Fig. 4. The amplitudes of the stator currents in Fig. 4a) are constant this time and do not vary with mechanical speed. The vector control is able to compensate effectively for the speed variation and the stator power output is constant. However, the converter needs to consume or supply certain amount of active power in order that the stator currents can be controlled and this active power is drawn from or returned to the power grid. This amount goes up with the difference The amplitude of between the mechanical and synchronous speeds of the machine. As the entire generated power of the unit consists of both stator and rotor powers, it contains power pulsations of the same frequency as the pulsations in speed. The amplitude of these pulsations is just about 1%, which is much less than in the case of the induction generator. It is evident from Fig. 4c) that the produced electromagnetic torque of the machine is kept constant with this type of control.

Last, an improved vector control method that compensates for the active power drawn from the power network by the converter supplying the rotor winding was proposed and analyzed. A simplified scheme of this vector is shown in Fig. 5.

The reference signal was modified in order that the rotor rotor power could be taken into account and the entire power generated by the machine could be controlled. The currents in Fig. 5a) seem to be the same as in the previous case, but there is a small difference that results in almost absolute compensation of the generated power pulsations. The complete power generated by the machine is constant in Fig. 5b). This was achieved by means of changing the stator power of the machine and so the input power of the converter was compensated. The electromagnetic torque varied accordingly.



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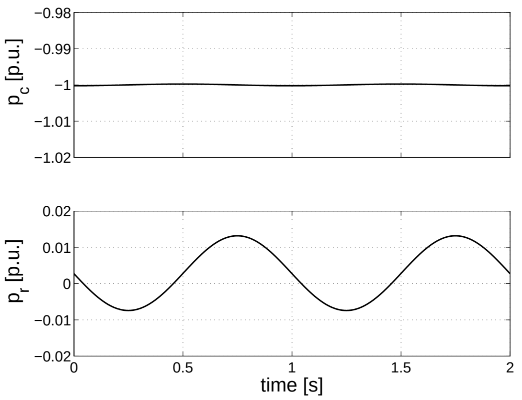

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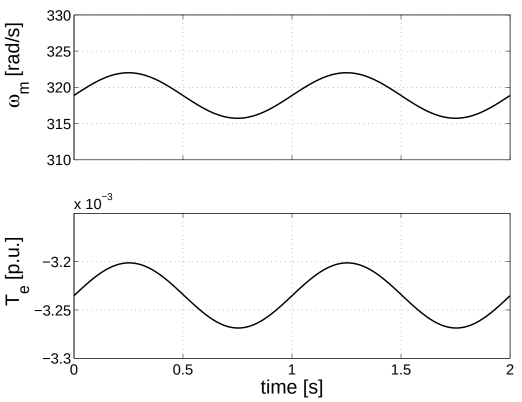

c)

Fig. 5. Operation of unit with doubly fed machine – modified control.

4. Conclusion

As it has been shown in the paper, it is possible to compensate effectively for the varying wind speed and tower shadow effect using power unit with doubly fed machine in order to reduce the flicker effect in the power grid. The control algorithm would also be able to compensate for larger wind gusts as far as the energy storage capability of the rotating masses suffices to deliver or consume the resulting power pulsations. A modified vector control method has been presented. It also compensates for the power consumed or produced by the converter in the rotor circuit of the doubly fed machine.

Further work should be aimed at the effect that the use of doubly fed machine controlled in such way has on the mechanical properties of the wind turbine.

Acknowledgement

This work was supported by the Grant Agency of the Czech Republic under research grant No. 102/03/0046.

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