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Development of an experimental investigation procedure on double fed electric machine-based actuator for wind power systems

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Abstract

The implementation and the experimental validation of a double fed machine-based actuator operating as double output induction generator in a wind energy conversion system are presented. The system performance is studied considering the variations of the excitation voltage, the excitation frequency and that of the wind speed. The obtained results show the limits of stable operation and also indicate the possibilities of this system in order to better utilise the wind energy.
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Keywords: Actuator; Double output induction generator; Wind energy conversion system

1. Introduction

World-wide, there is a continued demand for new configurations in power engineering, especially in electric power generation from renewable energy sources. In the last few years, the double fed electric machines receive an increasing attention due to their use as motors in high power variable speed industrial drives and as generators in wind power plants. They exhibit high performance in both modes of operation and, as a result, there is an increasing interest for the study of their dynamics for the development of new control methods [1,2].

An induction machine-based actuator can operate either as motor in conditions of double supply or as generator in conditions of double output. When operating in a variable speed environment such as the wind power fluctuations and generating a variable, voltage–variable frequency output can be considered as a multi input–multi output system. Its input variables are the rotor excitation voltage, the rotor excitation frequency and the driving wind torque, while its output variables are the generated voltage and the generated frequency at stator terminals. This system has a fifth-order state-space model and the study of its dynamics, as reported in previous publications, shown that its transient stability is influenced by disturbances of speed and excitation frequency [3–6].

This paper presents the implementation, the experimental investigation and the results obtained for a double fed induction machine-based actuator operating as double output induction generator (DOIG) in a wind energy conversion system (WECS). The system performance is studied considering the variations of the excitation voltage, the excitation frequency and that of wind speed. In all situations, the system load is kept constant at a selected level in order to study the operation of this system for low wind energy penetrations.

The results obtained show the limits of stable operation and also indicate the procedure for utilising this system in WECS.

2. Experimental system

The DOIG based actuator is shown in Fig. 1. In this configuration, the rotor windings are connected to an inverter unit, which supplies to the machine the excitation voltage U_r and the excitation slip frequency f_r. The generated stator voltage and frequency vary when the actuator is not connected to the grid and operates autonomously. In other situations, such as grid connected induction generator, the generated stator voltage and frequency are constant.

The actuator consists of a 1 kW, four pole, wound rotor induction machine, a single phase uncontrolled rectifier and a three phase PWM inverter. The rectifier converts the line voltage to dc voltage and the PWM inverter converts the dc voltage to three-phase ac voltage U_r at slip frequency f_r,

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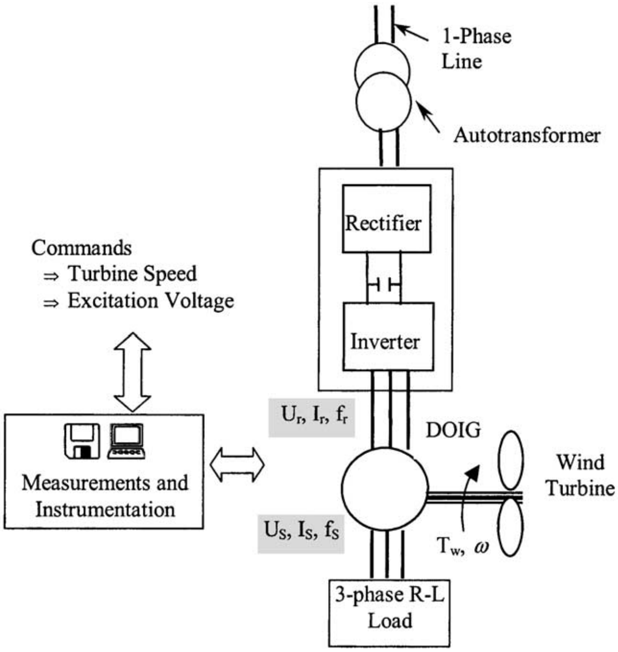

Fig. 1. DOIG actuator system block diagram.

which is supplied to the rotor windings. The stator windings are connected to a three-phase *R–L* load because of the autonomous operation and supply voltage U_s at frequency f_s. A dc motor simulates the wind turbine, which is mechanically connected to the generator shaft and produces the mechanical energy with a driving torque T_w and rotational speed ω.

The DOIG, the dc motor and the inverter are interfaced to the Measurements and Instrumentation unit, which contains the signal conversion devices, the digital scope, the measuring instruments and produces the outputs to the operator. Also, the operator selects the turbine speed, the excitation voltage and frequency command.

3. Results

The experimental results obtained for the DOIG actuator were studied considering variations of excitation voltage U_r, variations of excitation frequency f_r and variations of wind speed ω. During the tests the system load was constant at $R = 130\,\Omega$, $R = 90\,\Omega$ and $R = 70\,\Omega$ while $L = 0$ H.

Fig. 2 shows the generated voltage U_s and excitation voltage U_r during the increase of wind speed from 1450 to 1800 r/min at constant excitation frequency. In order to maintain constant machine flux independent of changes in the generator speed, the excitation voltage to excitation frequency ratio is kept constant, as can be observed from this figure. At constant excitation frequency f_r, the rotor voltage U_r remains constant while at the same time the increase of the wind speed ω increases the generated voltage U_s. Around synchronous speed, from 1450 to 1550 r/min, the excitation voltage is increased by adding a boost value of

Fig. 2. Generated voltage and excitation voltage drring speed variations ($R = 90\,\Omega$ $f_r = 30$ Hz): U_s (◇), U_r (□).

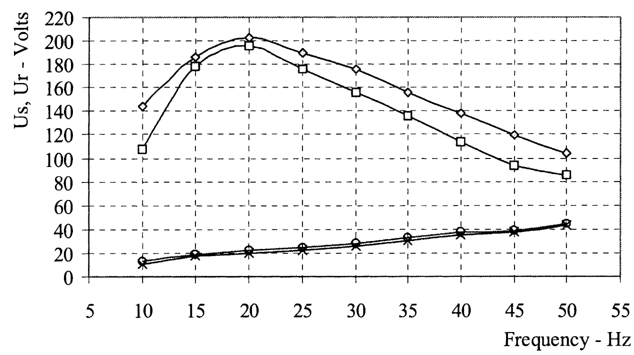

Fig. 3. Stator and rotor voltage measurements during variations of excitation frequency at varying loads: U_s, 130 Ω (◇); U_s, 90 Ω (□); U_r, 130 Ω (O); U_r, 90 Ω (×).

8–10 V in order to overcome the almost zero slip region of operation.

Figs. 3 and 4 show the voltages and currents (stator and rotor) of the DOIG, respectively. Both figures present experimental results obtained considering the variations of excitation frequency at the rotor side from 10 to 50 Hz, and with the system load at two different values, 90 Ω and 130 Ω. In Fig. 3, it is easily observed that the constant rate of excitation voltage/excitation frequency condition in order to maintain constant flux independent of changes in the excitation frequency f_r. If the ratio U_r/f_r remains constant during

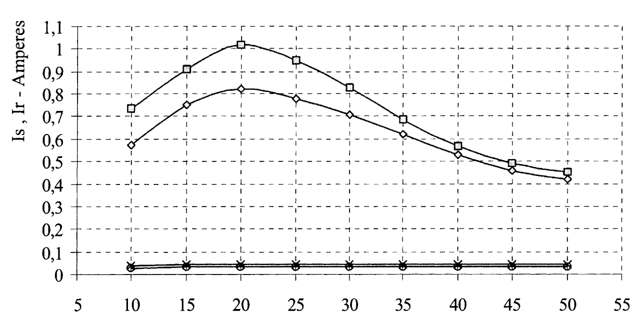

Fig. 4. Stator and rotor currents measurements during variations of excitation frequency at varying loads: I_s, 130 Ω (◇); I_r, 130 Ω (O); I_s, 90 Ω (□); I_r, 90 Ω (×).

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