INVESTIGATION ON DOUBLY FED INDUCTION GENERATOR STEADY STATE PARAMETERS

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Abstract - In this paper steady state characteristic of a variable speed Doubly fed induction generator (DFIG) is investigated. Torque and speed is used as design parameters for DFIG. From mathematical model it is found that on increase of rotor injection voltage and resistance, the torque speed response is shifted from over synchronous to sub synchronous range. The stability of DFIG operation is entirely dependent on torque. The functional relationship of generator further validated using MATLAB and experimental model. DFIG find application mainly in wind energy conversion system.

Keywords - *Asynchronous Operation, Doubly fed induction generator (DFIG), Rotor resistance, Wind energy.*

I. INTRODUCTION

The growing demand of energy in industrialized world and environmental problems determined some important decision at political level that consider even more important to improve the percentage of energy produced by renewable sources[1]. A lot of efforts are devoted to increase the efficiency of the generation systems based on wind, sun, hydro and biomass.

Wind power is one of the most interesting technologies, especially considering the developments in the last decade. The electrical energy generation by wind depends on different factors, in particular the wind speed and the characteristics of the wind turbine generator [2]. There are different technical solutions that have been set up for different cases, for wind turbines in a range from less 1 kW to as large as 3 MW or more, to obtain the maximum efficiency and reliability. Traditionally the wind power generation has used fixed speed induction generators that represent a simple and robust solution, and then variable speed turbines have been considered. The advantages of variable speed turbines is that they provide higher energy, allow an extended control of both active and reactive power and present less fluctuation in output power.

Both induction and synchronous generators can be used for wind turbine systems. Induction generators can be used in a fixed speed system or a variable-speed system, while synchronous generators are normally used in power electronic interfaced variable-speed systems. Mainly, three types of induction generators are used in wind power conversion systems: cage rotor, wound rotor with slip control by changing rotor resistance, and DFIG [6]. The cage rotor induction machine can be directly connected into an ac system and operates at a fixed speed or uses a full-rated power electronic system to operate at variable speed. The wound rotor generator with rotor resistance- slip control is normally directly connected to an ac system, but the slip control provides the ability of changing the operation speed in a certain range. The DFIG provides a wide range of speed variation depending on the size of power electronic converter systems. In this paper we discuss the systems without power electronics.

Doubly-fed induction machines can be operated as a generator as well as a motor in both sub synchronous and super synchronous speeds, thus giving four possible operating modes. Only the two generating modes at sub synchronous and super synchronous speeds are of interest for wind power generation. In a DIFG the slip rings are making the electrical connection to the rotor [3-4]. If the generator is running super-synchronously, electrical power is delivered to the grid through both the rotor and the stator. If the generator is running sub-synchronously, electrical power is delivered into the rotor from the grid.

II. STEADY STATE ANALYSIS OF DOUBLY FED INDUCTION GENERATOR

The steady state performance can be described by using equivalent circuit model shown in fig. 2.1[5], where motor convention is used. In this figure, V_S and V_R are the stator and rotor voltages, I_S and I_R are the stator and rotor current, R_S and R_R are the stator and rotor resistance, X_S and X_R are the stator and rotor leakage reactance, X_M is the magnetizing reactance and s is slip.

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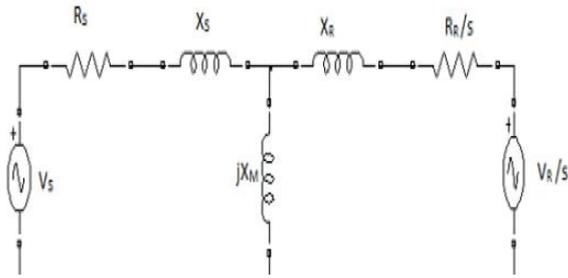
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Fig. 2.1 : DFIG equivalent circuit with injected rotor voltage

The rotor current (I_R) can be calculated from

$$I_R = \frac{V_S - \frac{V_R}{s}}{(R_S + \frac{R_R}{s})^2 + j(X_S + X_R)^2}$$

(1)

The torque (T) of the machine which equates to the power balance across the stator to rotor gap can be

$$T = I_R{}^2 \frac{R_R}{s} + \frac{P_R}{s}$$

(2)

Where the power supplied or absorbed by

$$P_R = \frac{V_R}{s} I_R \cos\theta$$

$$P_R = Re(\frac{V_R}{s} I_R^*)$$

(3)

where $I_R{}^*$ is active rotor current

III. STEADY STATE CHARACTERISTICS OF DOUBLY FED INDUCTION GENERATOR

It is a way to investigate of operating regularities of DFIG characteristic curves through simulation. Typical characteristic curves of a DFIG are torque versus speed and real power versus speed characteristics. In induction machine those characteristics depend on the injected rotor voltage in addition to applied stator voltage.
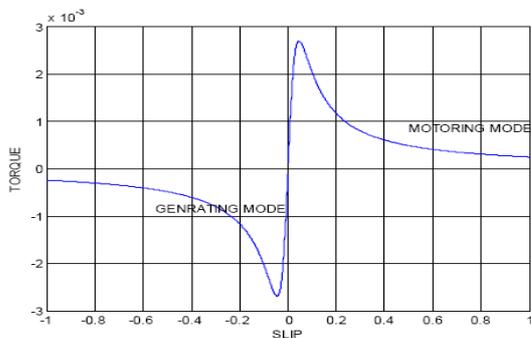

Fig. 3.1: Torque speed characteristics of DFIM

A conventional fixed-speed induction machine operates in generating mode for $-1 < s \leq 0$ and motoring mode for $0 < s \leq 1$. Fixed-speed induction machine, a DFIM can run both over and below the synchronous speed to generate electricity. Fig.3.1 shows a simulated DFIM torque-speed characteristic for an injected rotor voltage as the operating slip varies from s=-1 to s = 1. It can be seen from Fig.3.1, the DFIM generating mode, corresponding to the negative torque values can extend from negative slip (super synchronous speed) to positive slip (sub synchronous speed).
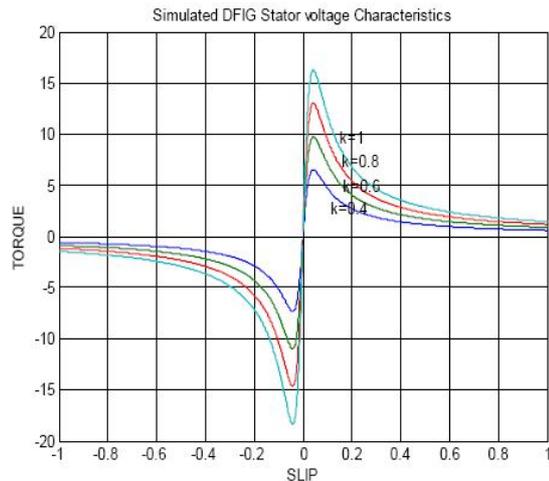

Fig. 3.2 : Simulated DFIG Stator Voltage Characteristics

The torque is proportional to the square of the stator supply voltage and a reduction in stator voltage can produce a reduction factor in speed voltage. Fig.3.2 shows torque speed characteristics for various value of reduction factor (k).
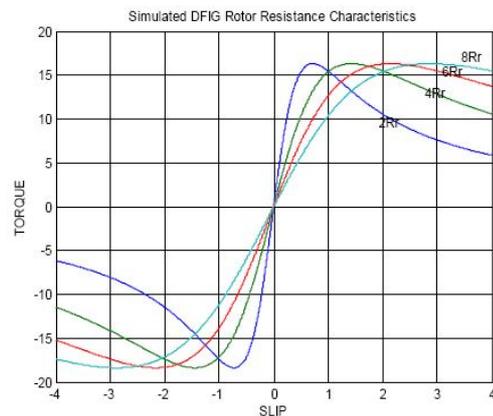

Fig. 3.3 : Simulated DFIG Rotor Resistance Characteristics

The slip at maximum torque is directly proportional to rotor resistance R_r but the value of torque is independent of R_r. When R_r is increased by inserting external resistance in the rotor of a wound rotor motor, the torque is unaffected but the speed at

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which it occurs can be directly controlled. The results are shown in fig.3.3.

Fig.3.4 shows the real power as V_q increased from 0.2 to 0.6pu while V_d is kept constant at 0pu.
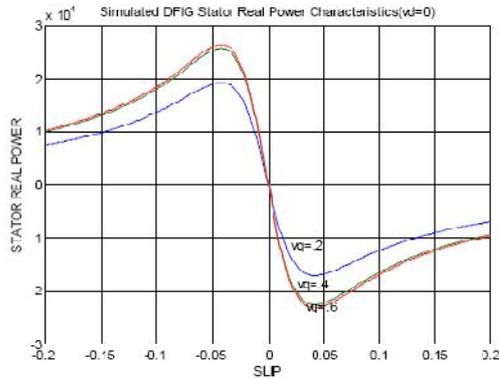

Fig. 3.4 : Simulated DFIG Stator Real Power Characteristics (V_d =0)

Examining these curves reveals the following:

- Either V_q or V_d component of the rotor injected voltage increases positively, the DFIG real power generation characteristics shifts more into sub synchronous speed range.

- V_q or V_d increases positively, the generation pushover power of a DFIG rises too, showing increased DFIG stability and power generation capability.

- V_d changes from negative to positive, DFIG real power changes gradually from flowing into (motoring) to flowing out of (generating) the induction machine.
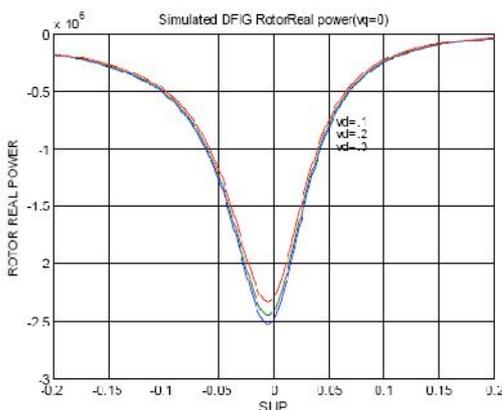

Fig. 3.5 : Simulated DFIG Rotor Real Power Characteristics (V_q=0)

Fig.3.5 shows the real power as V_d increased from 0.1 to 0.3pu while V_q is kept constant at 0 pu. Examining these curves reveals the following:

- For both motoring and generating modes, the DFIG sends an additional real power through its rotor as shown in Fig. 3.5.

- For high values of the injected rotor voltage, the real power delivered to the DFIG rotor is maximum at synchronous speed at which the DFIG rotor is equivalent to a short circuit. A proper control of Vq and Vd is essential to prevent high currents flowing in the rotor.

IV. CONCLUSION

From the simulation analysis it is concluded that the DFIG characteristics are affected by its injected rotor voltage. Within variation in amplitude of the rotor injected voltage, the DFIG torque speed characteristics are shifted from over synchronous to sub synchronous speed range to generate electricity. It also increases the DFIG pushover torque, thereby improving the stability of operation. With increase in rotor injected voltage, the pushover power of the DFIG rises.

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APPENDIX

0.37KW, Rated Voltage 380V, Rated Current 1.2A

R_S (Stator Resistance) 0.083pu

X_S (Stator Reactance) 0.1055pu

R_R (Rotor Resistance referred to Stator side) 0.587pu

X_R (Rotor Reactance referred to Stator side) 1.285pu

X_M (Magnetizing Reactance) 0.0032 pu

Frequency 50 HZ

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