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Study of Doubly Fed Induction Generator Characteristics

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***Abstract*– The doubly fed induction generator (DFIG) is a variable speed induction machine that is utilized in modern wind turbine generators. In this paper steady state characteristic of DFIG is studied. 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

Wind power is today's most rapidly growing renewable energy source. Unlike conventional power plants that use synchronous machines as generators, induction machines are utilized in most commercial wind turbines for large wind power plants [1]. The behavior of the synchronous machines for grid power generation has been investigated for a long time. Yet, induction generators are not normally used for power generation in a traditional power plant, although substantial effort has been spent on investigating induction motors. The doubly-fed induction generator (DFIG) is an adjustable-speed induction machine that is widely employed in modern wind power industry [2, 3]. Wind turbine manufacturers are increasingly moving to variable speed concepts because of the following reasons. (1) Variable speed wind turbines offer a higher energy yield in comparison to constant speed turbines. (2) The reduction of mechanical loads and simpler pitch control can be achieved by variable speed operation. (3) Variable speed wind turbines offer extensive controllability of both active and reactive power. (4) Variable speed wind turbines show less fluctuation in output power [1, 2].

However, the performance of a DFIG depends not only on the induction generator, but also on how it is controlled. In order to understand DFIG power generation characteristics, various techniques have been developed to investigate the behavior of a DFIG under different d-q control conditions.

Traditionally, the steady-state study of a DFIG is primarily based upon the conventional squirrel-cage induction machine equivalent circuit with an applied rotor voltage. Yet, this applied rotor voltage has no connection to any d-q vector control mechanism applied to the generator, making it unable to investigate DFIG characteristics under different d-q vector control conditions in a steady-state environment[4]. Another hindrance for the steady-state-based characteristic study is that a vector-controlled mechanism requires a preselected orientation frame that is hard to trace.

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.

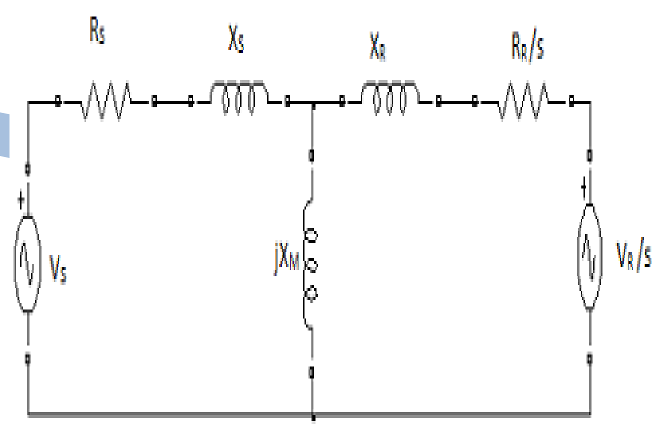

Fig. 2.1 DFIG equivalent circuit with injected rotor voltage

The rotor current (I_R) can be calculated from

$$I_R = \frac{V_S - \frac{V_R}{s}}{(R_S + \frac{R_R}{s})^2 + j(X_S + X_R)^2} \qquad (1)$$

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

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

Where the power supplied or absorbed by

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

$$P_R = Re(\frac{V_R}{s}\, I_R^*) \qquad (3)$$

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

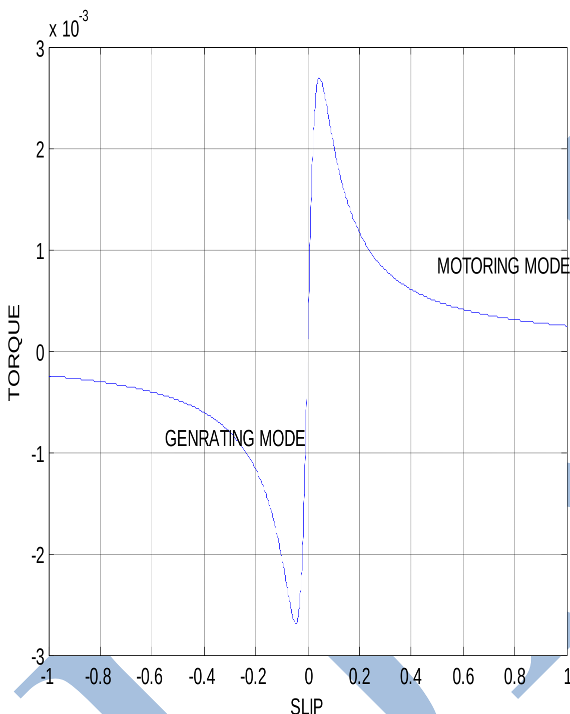

Fig.3.1 Torque speed characteristics of DFIG

A conventional fixed-speed induction machine operates in generating mode for -1< s ≤0 and motoring mode for 0< s ≤1. Fixed-speed induction machine, a DFIG can run both over and below the synchronous speed to generate electricity. Fig.3.1 shows a simulated DFIG 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 DFIG generating mode, corresponding to the negative torque values can extend from negative slip (super synchronous speed) to positive slip (sub synchronous speed).

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).

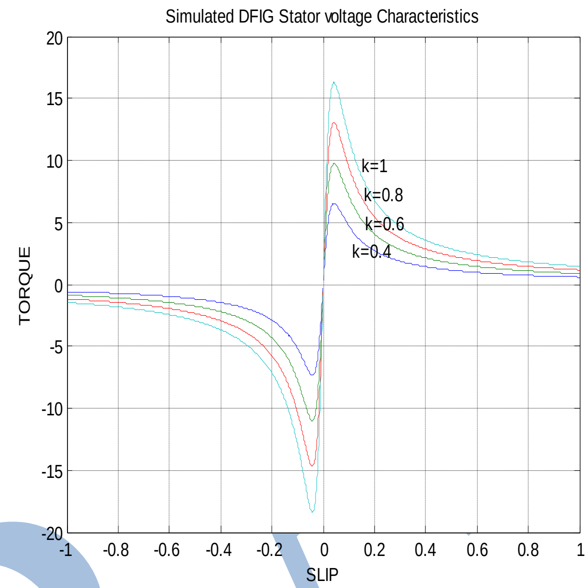

Fig. 3.2 Simulated DFIG Stator Voltage Characteristics

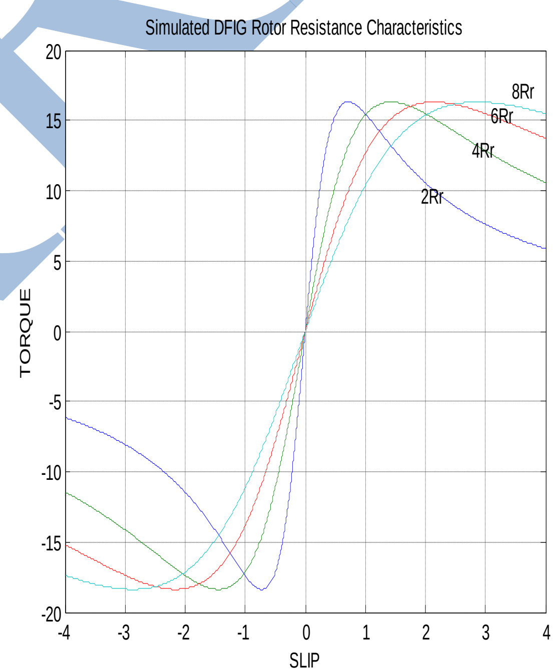

Fig. 3.3 Simulated DFIG Rotor Resistance Characteristics

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 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.

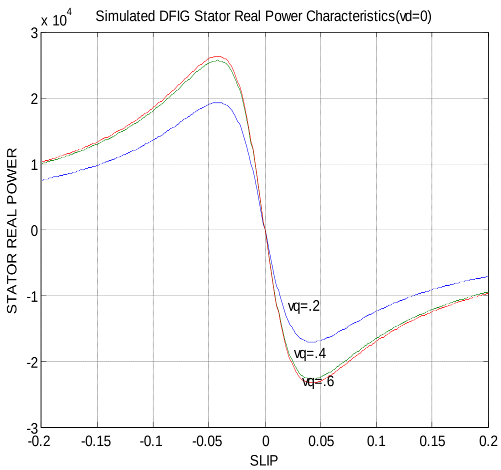

Fig.3.4 Simulated DFIG Stator Real Power Characteristics (V_d =0)

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.

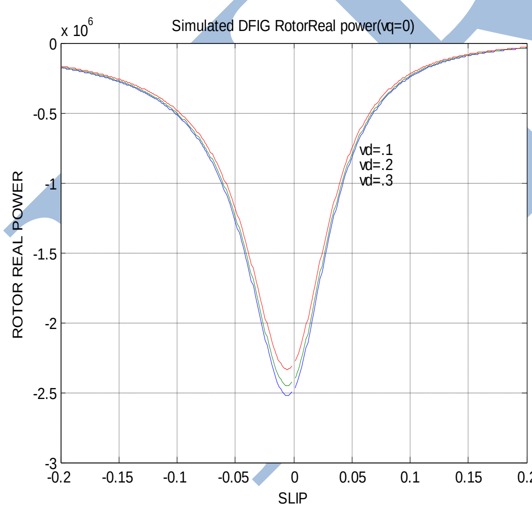

Fig.3.5 Simulated DFIG Rotor Real Power Characteristics (Vq=0)

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 V_q and V_d 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

